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THESIS

PLANNING CAPITAL INVESTMENTS IN NAVY FORCES

by

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Naval spending has always involved large amounts of resources, research and technology, money, and the attention of civilian and military leadership. In 1794 the Congress authorized $800,000 (1794 dollars) to construct six frigates. Today, an attack submarine costs more than $2 billion, an aircraft carrier more than $5 billion, and its air wing $5 billion more. These ships are the only current American clients for nuclear power plants. The Navy must balance these large capital expenditures with other procurements and maintain an industrial base capable of producing these unique warships. The Navy currently manages these complex interplays via the Integrated Warfare Architecture Assessment Planning Process (IWARS). Force Structure, an IWARS component, views a 25-year horizon at the platform level using the Extended Planning Annex/Total Obligated Authority Model (a spreadsheet that estimates the financial impact of any complete future plan). This thesis presents an integer-linear program, the Capital Investment Planning Aid (CIPA), that extends EPA/TOA with optimization. CIPA explores all alternatives while considering budget restrictions, industrial base requirements and restrictions, and force level requirements. CIPA is tested with a 25-year planning horizon with eight mission areas, 19 ship classes, five aircraft types, five production facilities, and three categories of money. A current base case and several excursions demonstrate CIPA can be used to address exigent issues optimally.

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PLANNING CAPITAL INVESTMENTS IN NAVY FORCES

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ABSTRACT

Naval spending has always involved large amounts of resources, research and technology, money, and the attention of civilian and military leadership. In 1794 the Congress authorized $800,000 (1794 dollars) to construct six frigates. Today, an attack submarine costs more than $2 billion, an aircraft carrier more than $5 billion, and its air wing $5 billion more. These ships are the only current American clients for nuclear power plants. The Navy must balance these large capital expenditures with other procurements and maintain an industrial base capable of producing these unique warships. The Navy currently manages these complex interplays via the Integrated Warfare Architecture Assessment Planning Process (IWARS). Force Structure, an IWARS component, views a 25-year horizon at the platform level using the Extended Planning Annex/Total Obligated Authority Model (a spreadsheet that estimates the financial impact of any complete future plan). This thesis presents an integer-linear program, the Capital Investment Planning Aid (CIPA), that extends EPA/TOA with optimization. CIPA explores all alternatives while considering budget restrictions, industrial base requirements and restrictions, and force level requirements. CIPA is tested with a 25-year planning horizon with eight mission areas, 19 ship classes, five aircraft types, five production facilities, and three categories of money. A current base case and several excursions demonstrate CIPA can be used to address exigent issues optimally.

DISCLAIMER

The reader is cautioned that the computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the planner.

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LIST OF ACRONYMS

ADEPT	Advanced Dynamic Evolutionary Process Tool
APN	Aircraft Procurement Navy
ARADA	Anti-armor Resource Allocation Decision Aid
CIPA	Capital Investment Planning Aid
CIVPERS	Civilian Personnel
EPA/TOA	Extended Planning Annex/Total Obligation Authority
FHN	Family Housing Navy
FYDP	Fiscal Years Defense Plan
IWARS	Integrated Warfare Architecture and Planning Process
JSFN	Joint Strike Fighter, Navy Variant
LCAC	Landing Craft Air Cushion
MILCON	Military Construction
MILPERS	Military Personnel
MPN	Military Pay Navy
NDSF	National Defense Sea-lift Fund
OMN	Operation and Maintenance
OPN	Other Procurement Navy
OSCAM	Operating and Support Cost Analysis Model
OSD	Office of the Secretary of Defense
PANMC	Procurement of Ammunition Navy/Marine Corps
QDR	Quadrennial Defense Review
RAD	Resource Allocation Display
RDT&E	Research Development Technology and Experimentation
SCN	Ship Conversion Navy
TOA	Total Obligation Authority
VAMOSC	Visibility and Management of Operation and Support Cost
WPN	Weapons Procurement Navy

EXECUTIVE SUMMARY

Naval procurement has always involved large amounts of resources, research and technology, money, and the attention of civilian and military leadership. In 1794, President Washington personally persuaded the Congress to authorize a budget of $800,000 (1794 dollars) to construct six frigates. Today, a single attack submarine costs more than $2 billion, an aircraft carrier more than $5 billion, and its air wing $5 billion more. These ships are the only current American clients for nuclear power plants. The Navy must balance these large capital expenditures with other procurements and maintain an industrial base capable of producing these unique warships.

The Navy manages procurement via its Integrated Warfare Architecture Assessment Planning Process (IWARS). Force Structure, an IWARS component, views a 25-year horizon at the platform level. One of their primary objectives is to quantify, in dollar and capability terms, the effect of Ship Conversion Navy (SCN) and Aircraft Procurement Navy (APN) programs in the Navy. To meet this objective they use the Extended Planning Annex/Total Obligated Authority Model (EPA/TOA), a spreadsheet that estimates the financial impact of any complete future plan. It is up to the analyst to manually specify all the proposed details for any given scenario over the entire planning horizon --- a daunting task --- to ensure that force level requirements are met and critical industrial facilities have adequate work to maintain Navy unique construction skills. Consider that the IWARS Force Structure analysts develop alternate yearly force structures over a 25-year horizon for over 100 platforms, with each alternative accounting for numerous platform retirements and the 14 major procurement programs in process or under consideration.

This thesis presents an integer-linear program, the Capital Investment Planning Aid (CIPA), designed to enhance the EPA/TOA model by using optimization to replace much of the manual work and thereby help analysts evaluate alternate force structures. CIPA recommends the best yearly force structure procurement plan based on industrial constraints, fiscal constraints, force level requirements, and force mix requirements. It

illuminates key decisions such as purchase dates and rates, the inability to meet procurement requirements due to financial constraints, and resource conflicts. Additionally, CIPA produces results that are consistent with the most recent force structure recommendations that are presented in the Fiscal Years Defense Plan and allows budget violations that can be repaid by other savings in the future.

CIPA has been tested with a 25-year planning horizon with eight mission areas, 19 ship classes, five aircraft types, five production facilities, and three categories of money. To demonstrate CIPA, a baseline case provides a benchmark for later excursions. The baseline reveals that attack Submarine force levels cannot be maintained at the Quadrennial Defense Review (QDR) specified level of 50. This turns out to be a consequence of an assumption that limits production of SSN774 class submarines to two submarines a year --- an assumption made to reflect initial joint synchronous production at Electric Boat and at Newport News shipyards. CIPA recommends small over-expenditures in Fiscal Years 13, 17, 18, and 19. Fortunately, these over-expenditures occur far enough in the future that they can be dealt with and balanced with lower spending in earlier and subsequent years. In another excursion, submarine production is increased to four per year, attack mission requirements are thereby met, the total amount expended over the entire planning horizon is greater than for the baseline, and CIPA recommends over-expenditures in Fiscal Years 16 and 18, but the total is less for this excursion than for the baseline. The total amount expended over the entire planning horizon is greater for this excursion due to the restriction to procure more SSN774 class submarines.

A critical insight here is that EPA/TOA will only evaluate a scenario completely specified in every detail: EPA/TOA is a purely *descriptive* model. By contrast, CIPA accepts the rules governing scenarios --- the constraints --- and recommends the *best* alternative among multitudes. CIPA is a *prescriptive* model. CIPA also recommends solutions so attractive that they warrant small violations of constraints --- these solutions are frequently insightful and persuasive. Although CIPA can be restricted to echo a completely fixed plan, and thus mimic EPA/TOA, it is the optimization that searches for

and reports the best plan among many that is the distinguishing advantage of CIPA over EPA/TOA.

The CIPA proof prototype offers unprecedented opportunity for force structure planning. CIPA is the only known navy model that integrates APN and SCN procurements with fiscal, industrial, and mission requirements to render the best integrated advice. CIPA demonstrates the potential of optimization-based capital budgeting models for the Navy.

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I would like to thank Professor Robert Dell for his insight, persistence, and guidance through this effort. He was ever ready to provide his mathematical programming techniques, organizational advice, and GAMS expertise to assist in my endeavors.

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Finally, I would like to thank my wife, Michelle, and my children, Justin and Hannah. They sacrificed many bedtime stories and sunny days with Dad so I could go to school to "do work." Thank you for your patience and understanding. I will always love you.

I. INTRODUCTION

We will study the Navy's capital planning system, which is only part of a complicated Department of Defense budget planning process. How did this process get so complex?

American defense budgeting began during the Revolution with proposed requisitions for fielding men and armaments, hand-written by the few well-known general officers who were preparing to personally lead these military operations. These requests were for "what I need." This requirements-based process persevered with some embellishment until after World War II, when the Hoover Commission required in 1948 that budgets be defended in terms of function and activities, rather than just numbers of men and amounts of materiel. The Defense Department and its staffs asked for "what we need to be able to achieve these things, by these specific means." "In 1959, General Maxwell Taylor suggested a 'mission-oriented' budget… Congress subsequently asked that the budget for fiscal 1961 be based on 'functional categories.' The idea was to replace intermediate military 'inputs' by strategic 'outputs' directly describing the policy's intended effects… [Martin 1988]." Subsequently, Secretary of Defense Robert McNamarra introduced the 5-year budget programs and a penchant for detailed decision-support that still characterizes defense budgeting. Now, we start with strategy, express this in terms of mission areas, and then eventually expand these into actual requirements for personnel, materiel, and, in particular, major weapons systems.

Naval spending has always involved large amounts of resources, research and technology, money, and attention of civilian and military leadership. In 1794, President Washington asked the United States Congress to authorize construction of six frigates at six different sites to help protect American merchant fleets from attacks by Algerian pirates and harassment by British and French forces [Hagan 1978]. With a total budget exceeding $800,000 (1794 dollars), congressional debate was intense, but construction was ultimately approved on the condition that it be conducted exactly as proposed in six different constituencies, thus affording political insulation. In fiscal year 1999 dollars, the

frigates would cost $2.6 billion [Vargo 1999]. The USS Constitution, shown in Figure 1, employed revolutionary technology, used more than 1,500 trees felled from Maine to Georgia and was armed with cannons cast in Rhode Island [USS CONSTITUTION 1999]. At the Battle of Trafalgar in 1805, Nelson's flagship was 46 years old; navies of today usually reckon half that as the maximum life of a warship. In 1863, President Lincoln formed the National Academy of Sciences to draw on the best academic and engineering talent in America to advise the Navy which new revolutionary technologies to adopt for the Civil War. Today, an attack submarine costs more than $2 billion, an aircraft carrier more than $5 billion, and its air wing $5 billion more. These ships are the only current American clients for nuclear power plants. The Navy must balance these large capital expenditures with other procurement and maintain an industrial base capable of satisfying its unique requirements. As we have learned in two World Wars, it is essential to maintain --- perhaps even by managing competition --- domestic defense industries in times of peace and industrial consolidation.

Figure 1. The USS Constitution exhibited innovative naval architecture and the latest aremanment technology (Figure from – [All Hands 1997]). Construction of the Constitution was planned and approved at the highest levels of American government, and required a nationwide mobilization of resources.

Navy budget analysts must continually respond quickly to scenarios arising from emergent world events and domestic politics. Their advice must consider the complex interplay between past decisions, politics, and fiscal realities. This thesis offers a new optimization tool to assist Navy planners to quickly arrive at the best advice.

The Navy's current effort to better manage the complex interplay is the Integrated Warfare Architecture Assessment and Planning Process (IWARS). IWARS promises to reduce inconsistencies and redundancies the old system admitted when sponsors pushed their own priorities without considering the overall requirements and capabilities of the Navy. IWARS also promises to ensure the Navy can contribute to the nation's joint force capabilities while addressing the complexity of Naval Warfare and the need to integrate programs when allocating scarce resources [Chief of Naval Operations 1999]. Force Structure, an IWARS component, views a 25-year horizon at the platform level (e.g., ships, submarines, aircraft) (see Figure 2). This thesis presents an integer-linear program, the Capital Investment Planning Aid (CIPA), that augments the Extended Planning Annex/Total Obligated Authority (EPA/TOA) model with optimization. CIPA explores all alternatives while considering budget restrictions, industrial base requirements and restrictions, and force level and mix requirements.

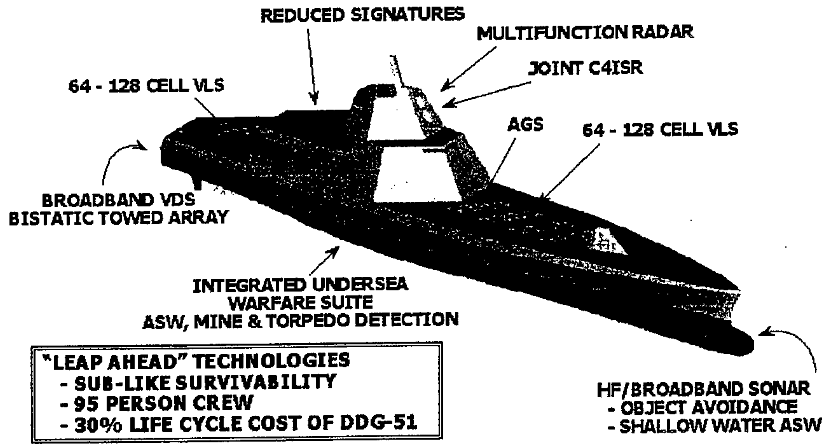

Figure 2. An artist's rendition of the Land Attack Destroyer (DD-21) (Figure from – [Director, Surface Warfare 1999]). This next-generation surface combatant will replace the aging Spruance (DD-963) class destroyers and the Oliver Hazard Perry (FFG-7) class frigates. The Navy plans to acquire 32 DD-21s at a rate of three ships per year beginning in Fiscal Year 2004 [Chief of Naval Operations 1999]. The planned cost for the DD21 are 750 million (FY96$) for the fifth ship and operation and support cost that are 70 percent lower than those of the DDG51 ship class [DD21 Program Executive Office 1999]. This thesis presents an integer-linear program that augments existing tools for exploring alternate yearly force structure plans at the platform (e.g., DD21) level. The program recommends yearly procurement and retirement rates over a 25-year horizon for 24 platforms while considering inventory requirements, fiscal constraints, and industrial constraints.

A. BACKGROUND

IWARS started in 1998 and is the responsibility of the Chief of Naval Operations Assessment Division (N81) [Chief of Naval Operations 1999]. IWARS consists of 12 integrated warfare architecture components. The primary IWARS components are Power Projection, Sea Dominance, Air Dominance, Deterrence, and Information Superiority/Sensors. The support IWARS components are Sustainment, Infrastructure, Manpower/Personnel, Readiness, Training/Education, Technology, and

Force Structure. The IWARS objectives are to provide end-to-end capability analysis of naval forces with a linkage between warfare and support components, measured performance, sequencing and synchronization of capabilities, and sound operational architectures. IWARS will provide detailed program planning inputs to the Chief of Naval Operations Program Assessment Memorandum separately from the Planning Programming and Budgeting System. These inputs will be persistent from year to year and fiscally bounded. [Valentine 1999]

The focus of the Force Structure component is "on assisting Navy leadership in best matching available resources with desired capabilities in the near, middle, and far terms" [Chief of Naval Operations 1999]. More specifically, the Force Structure component develops and analyzes alternate procurement and retirement plans for ships, submarines and aircraft (see Figure 3) that meet fiscal constraints [Valentine 1999]. One of their primary objectives is to quantify, in dollar and capability terms, the effect of Ship Conversion Navy (SCN) and Aircraft Procurement Navy (APN) programs.

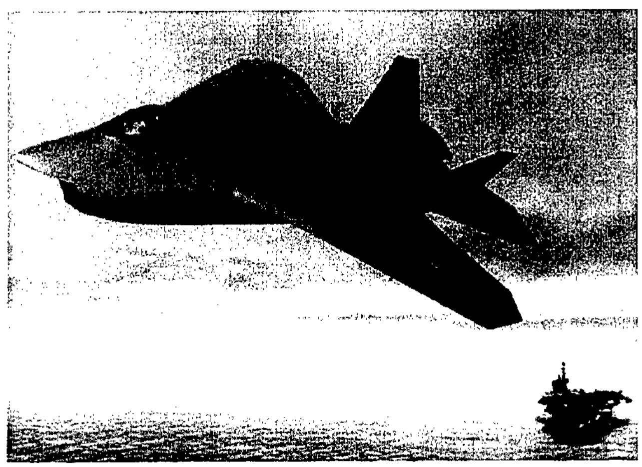

Figure 3. An artist's rendition of the Navy variant Joint Strike Fighter (JSF) (Figure from – [Joint Strike Fighter Program 1999]). The Navy variant of the JSF, the next generation strike aircraft, is being designed to compliment the F18 E/F [Joint Strike Fighter Program 1999]. Expected delivery of the first operational aircraft is Fiscal Year 2008 for the Marine Corps and Fiscal Year 2010 for the Navy [Director, Air Warfare 1999]. This thesis presents an integer-linear program that augments existing force structure planning tools. It allows analysts to do a more thorough job of exploring the combined effects of procuring the next generation ships and aircraft for the Navy and Marine Corps.

B. FORCE STRUCTURE ANALYSIS TECHNIQUES

The Extended Planning Annex/Total Obligated Authority (EPA/TOA) model is the primary tool used by N81 to evaluate specific alternate force structures. Based on inputs from the warfare IWARS components, resource sponsors, and numerous documented requirements such as the Quadrennial Defense Review (QDR), Defense Planning Guidance and Commanders in Chief operational plans, analysts perform manual what-if scenarios using the EPA/TOA model. Analysts then compare scenario results to determine the best structure that most closely matches projected budgets and meets force size and capability requirements.

Systems Planning and Analysis, Incorporated maintains the EPA/TOA model for N81. Systems Planning and Analysis [1998] states that the objectives of the EPA/TOA model are:

1) To accurately estimate long-range Navy TOA requirements at the appropriation level for a given yearly force structure.
2) Project aircraft and ship yearly force structure based on the current resource allocation, long-range procurement plans, delivery schedules, retirement schedules, expected service lives, attrition, and maintenance requirements.

The EPA/TOA model links sixty-two spreadsheets that calculate yearly Military Personnel (MILPERS), Civilian Personnel (CIVPERS), Military Pay Navy (MPN), Operation and Maintenance (OMN), Other Procurement Navy (OPN), Ship Conversion Navy (SCN), Aircraft Procurement Navy (APN), Procurement of Ammunition Navy/Marine Corps (PANMC), Weapon Procurement Navy (WPN), Research Development Technology & Experimentation (RDT&E), Military Construction (MILCON), Family Housing Navy (FHN), National Defense Sea-lift Fund (NDSF), and OTHER monies for input procurements and retirements. Figure 4 shows the structure of the model.

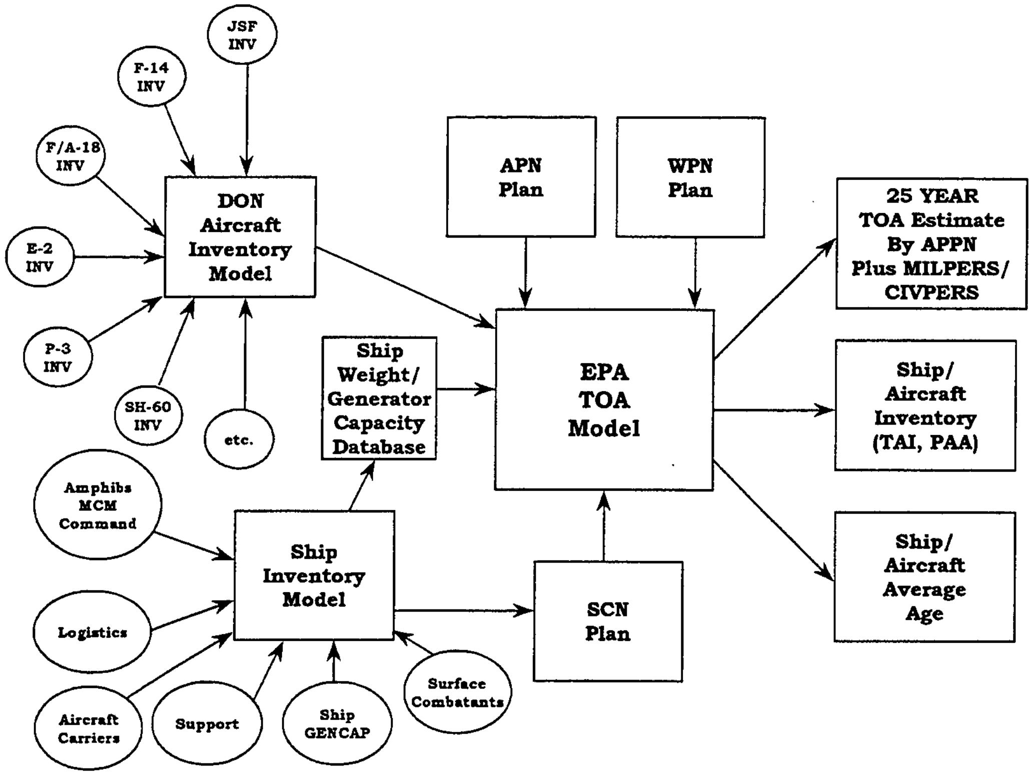

Figure 4. Extended Planning Annex/Total Obligated Authority (EPA/TOA) Model Structure [Systems Planning and Analysis 1998]. This model is the primary tool used by the IWARS Force Structure component for analysis. It consists of 62 spreadsheets that are linked to estimate Total Obligated Authority. This thesis provides an integer linear program to augment the EPA/TOA model with optimization.

The current Resource Allocation Display (RAD), a snapshot of the Fiscal Years Defense Plan (FYDP) at a specific point in time, is the basis for near-term cost, procurement, and retirement of weapons systems. The EPA/TOA model fixes TOA in the near term based on the FYDP. For the middle-term and far-term the analyst inputs procurements and retirements of weapons systems. The model calculates TOA based on cost estimation relations for MILPERS, CIVPERS, MPN, OMN, OPN, SCN, APN, PANMC, and WPN monies. The model uses cost analogies --- the multiplication of a historic data point by a scalar --- to estimate cost for RDT&E, MILCON, FHN, NDSF, and OTHER monies.

The force structure analysts are primarily concerned with the procurement and retirement of ships, submarines and aircraft. Ships are procured with SCN money and aircraft with APN money. Within EPA/TOA procurement of ships and aircraft directly affect SCN and APN, and indirectly affect some of the other TOA monies through their cost estimation relationship. A sample of the cost estimation relationship and analogies within the EPA/TOA model for SCN, APN, and OMN in the middle term are presented in Appendix A.

Using the EPA/TOA model for force structure analyses requires the analyst, for each possible force structure, to answer the following questions:

1) Have all documented force requirements outlined in the Quadrennial Defense Review, Defense Planning Guidance, Commanders-in-Chief operational plans and other instructions been met?
2) Have all industrial constraints been considered? For example, is a carrier always being built at Newport News and a submarine at Electric Boat? Has production capacity been exceeded at any shipyard?
3) Will future procurements and retirements satisfy force size and force mix requirements?
4) Will the proposed structure fall within the projected budget?
5) Have all spreadsheets been updated to reflect the proposed force structure?

The EPA/TOA model does an adequate job of estimating TOA for a specific force structure if the analyst has correctly answered these questions [Systems Planning and Analysis 1998]. The problem is that this is still essentially a manual process. For instance, to change the procurement plan for the DDG51 class ship requires an analyst to answer these questions and then synchronously make consistent changes to 3 different spreadsheets. This is very cumbersome and error-prone considering that the IWARS Force Structure analysts develop alternate yearly force structures over a 25-year horizon for over 100 platforms. Each alternative accounts for numerous platform retirements and the 14 major procurement programs in process or under consideration.

C. PURPOSE

This thesis presents an integer-linear program, the Capital Investment Planning Aid (CIPA) that uses EPA/TOA data, but eliminates the necessity to manually prepare complete scenarios, and generalizes the problem statement from EPA/TOA's "evaluate this solution" to CIPA's "derive the best solution within these guidelines." CIPA recommends a yearly force structure procurement plan based on industrial constraints (see Figure 5), fiscal constraints, force level requirements, and force mix requirements. It illuminates key decisions such as purchase dates and rates, the inability to meet procurement requirements due to financial constraints, and resource conflicts. Additionally, CIPA produces results that are consistent with the most recent force structure recommendations that are presented in the FYDP and allows budget violations that can be repaid by other savings in the future.

D. THESIS ORGANIZATION

Chapter II begins with an overview of models identified by N81 for use in force structure analysis and concludes with a literature review of military capital budgeting models.

The CIPA model is presented in Chapter III. Model assumptions are presented first and followed by the model formulation. The chapter concludes with a discussion of CIPA's elastic variables and penalties.

Implementation of and analysis with CIPA is described in Chapter IV. First baseline data and model results are presented. Results from the baseline case suggest several excursions that are examined.

Chapter V details conclusions and recommendations.

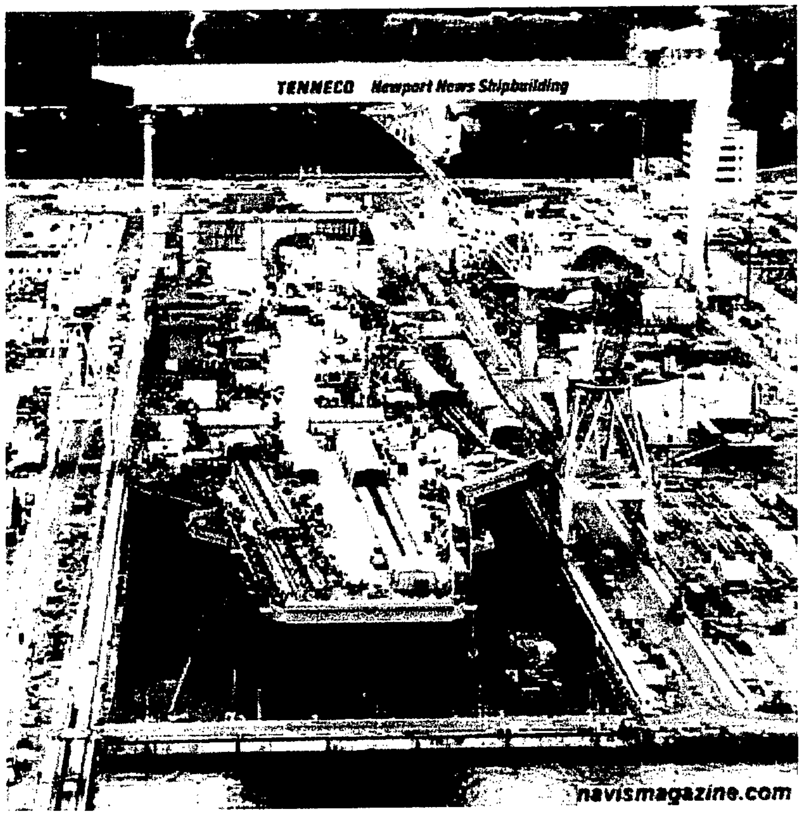

Figure 5. Nimitz-class nuclear-powered aircraft carrier construction at Newport News Shipbuilding (Figure from – [NAVISMAGAZINE 1999]), the sole shipyard in the United States capable of building nuclear-powered carriers. Critical industrial base technologies and skills such as those used to build carriers, submarines, and surface ships must be maintained. No civilian or commercial counterparts to these products exist and foreign sources cannot produce these ships for the Navy [Chief of Naval Operations 1999]. The Navy must procure ships at rates that maintain this domestic industrial base. The integer-linear program presented in this thesis schedules procurements so that minimum production requirements are met and the maximum capabilities of the associated shipyards are not exceeded.

II. IWARS MODELS AND LITERATURE REVIEW

A. FORCE STRUCTURE IWARS MODELS

Including the EPA/TOA model, three models exist and one model is under development for potential use in IWARS force structure analyses. Systems Planning and Analysis, Incorporated maintains the Extended Planning Annex/Total Obligated Authority (EPA/TOA) model, the model that is primarily used by N81. The Naval Center for Cost Analysis manages the other available models: the Navy's Visibility and Management of Operation and Support Cost (VAMOSC) and the Operating and Support Cost Analysis Model (OSCAM). These two models only estimate Operation and Support cost.

A model under development, Advanced Dynamic Evolutionary Process Tool (ADEPT), is a simulation model [Decision Dynamics Incorporated 1999]. Decision Dynamics advertises ADEPT as a "suite of five interrelated simulation models designed to help people understand and manage a product's entire life cycle from design, through production and operation." Once operational, ADEPT's initial contributions to force structure planning will most likely be in the form of Operation and Support cost and data estimates based on the effective age of individual ships. ADEPT, through simulation, will reportedly be able to model the effective age of a ship given its operating and maintenance schedules. Another potential ADEPT contribution is reportedly in the scheduling of procurements and retirements of ships and aircraft. Decision Dynamics claims ADEPT can use optimization to suggest alternate courses of action. In the future, ADEPT may have the ability to combine the effective age simulation with optimization and provide retirement and procurement schedules, though we do not see the quantitative foundation for doing so. This portion of ADEPT is not currently being funded by the Office of the Secretary of Defense and would reportedly require a minimum of one year to be operational [White 1999].

B. MILITARY CAPITAL BUDGETING OPTIMIZATION MODELS

Brown, Clemence, Tuefert, and Wood [1991] develop a large-scale capital budgeting model, named PHOENIX, to aid Army helicopter force planners modernize a fleet that was primarily composed of Vietnam era aircraft. Since PHOENIX, capital budgeting models have been used by the Army to modernize its fleet of tactical wheeled vehicles [Brown et al. 1991], and by the Air Force to create investment plans for the research and development of space-based systems [Newman et al. 1999]. Newman et al. provide an extensive literature review of both commercial and military capital budgeting optimization models; here we only describe military models that are similar to CIPA.

PHOENIX plans four actions: procurement of new aircraft on new production lines, changing existing production to incorporate necessary enhancements, applying service life extension programs to existing aircraft, and retiring obsolete aircraft. PHOENIX schedules these actions by trying to minimize Operation and Maintenance costs while ensuring that sufficient numbers of aircraft exist to meet mission requirements, that maximum average age restrictions for mission specific aircraft are not exceeded, that production requirements and restrictions are met, and that budget expenditures are acceptable. Given their projected budget, PHOENIX provided Army helicopter force planners with valuable insight that suggested: downsizing of the helicopter fleet was mandatory, mission area deficiencies were inevitable, and some existing helicopters were less cost effective than projected. PHOENIX also suggested that in order to adopt the most promising force structure alternatives, funding levels would need to be non-uniform and careful violation of policy constraints would be required. The PHOENIX model was credited with saving a new helicopter program that was on the brink of cancellation and with changing the Army's approach to planning modernization. The Army used the same approach employed in PHOENIX to plan the modernization of its tactical wheeled vehicles. The foundation for CIPA is the PHOENIX model.

Newman, Brown, Dell, Giddings, and Rosenthal [1999] present another large-scale military capital budgeting application in their technical report on the Air Force's Space Command Optimizer of Utility Toolkit (SCOUT). Their report provides a

description of SCOUT, model modifications, and computational experience. They describe SCOUT as "a mixed integer linear program that selects a set of concepts, the dates of inception and discontinuance of use, and the number of concept launches by type and year which best satisfy the Air Force Space Command's operational tasking requirements"[Newman et al. 1999]. SCOUT minimizes penalties associated with failure to meet task performance requirements, violating budget constraints, and penalties incurred from spending money that does not result in task performance gains. The constraints in SCOUT can be categorized into four types: budget constraints, performance requirements, precedence requirements and interdependency requirements. The budget constraints account for yearly budget limitations and restrictions on cost over a five-year time epoch. The precedence constraints ensure that primary systems are operational before subordinate systems. SCOUT is another example of a successful large-scale military capital budgeting model. A version of SCOUT was used by the Air Force Space Command to select concepts in 1997 [Newman et al. 1999].

Since PHOENIX, capital budgeting models have been presented in a variety of military applications. Donahue [1992] develops a multi-objective optimization model to help Army Training and Doctrine Command select which candidates to include in the Long Range Army Materiel Requirements Plan. The model objectives are to improve the Army's warfighting capability while maintaining mission area balance. The model is constrained by budget restrictions, congressionally mandated project requirements, incremental funding requirements, and project relationships that can be mutually exclusive, complementary, or subordinate.

Ihde [1995] develops the Anti-armor Resource Allocation Decision Aid (ARADA) model to assist the Department of Defense in determining anti-armor weapon procurement policy. ARADA seeks to maximize effectiveness across selected weapon systems. Weapon system selection is restricted by constraints on the budget and procurement. Gross [1996] creates a mixed integer program that expands on ARADA to allow selection of weapon systems across diverse mission areas.

Carr [1996] develops a mixed integer linear program to help the Ballistic Missile Defense Organization plan Theater Missile Defense system procurements. The model minimizes total procurement costs while meeting budget restrictions, operational requirements, scheduling restrictions, and weapon interdependency requirements.

Lastly, Loerch [1999] discusses how the Army uses optimization and cost estimation in the current descendent of Phoenix to plan purchases of weapons and equipment. Concave cost functions that arise as a consequence of learning effects are discussed, and piecewise linear approximation of these is demonstrated in a linear integer model.

III. MODEL FORMULATION

A. MODEL OVERVIEW AND ASSUMPTIONS

CIPA is an integer-linear program that recommends a yearly force structure procurement plan based on minimizing penalties for violating budget constraints, production constraints, or inventory requirements. For a recommended plan, it illuminates the required budget, purchase dates and quantities, production facility employment levels, and force levels. Additionally, it isolates force level deficiencies associated with budget mandated procurement levels, production that cannot keep pace with procurement requirements, or failure to identify replacements for retired platforms.

Because CIPA is designed to extend EPA/TOA, every effort has been made to mirror EPA/TOA. Major assumptions carried over from EPA/TOA include:

1) Procurement in the near term (FY00 to FY05) is fixed to follow the Fiscal Years Defense Plan;
2) Procurement costs are incurred in the first year of production or earlier. Costs are not spread out over the entire production period of a platform;
3) Operation and maintenance cost for a platform are incurred for the entire year of delivery;
4) Aircraft are delivered two years after procurement; and
5) All monies are in Fiscal Year 1999 million (FY99$M) dollars.

One last assumption, specific to CIPA, is that Total Obligated Authority (TOA) is completely constituted of just the categories of money represented in the model. For example, when aircraft and ship procurements are modeled, TOA is the sum of SCN, APN, and OMN. TOA is the sum of SCN, APN, OMN, and WPN if weapons procurement is added.

B. MODEL

1. Introduction

The model uses both binary and continuous decision variables to strike a balance between realism and solvability. The number of ships procured in a given year is relatively small, so these decisions are governed by binary variables. Aircraft procurements are generally made in larger numbers so they are represented by continuous variables. Inventory levels of operational ships and aircraft are represented by continuous variables for similar reasons. Additional binary variables are used to specify non-convex, piecewise linear cost functions used to approximate the EPA/TOA cost functions.

The model uses "elastic" [e.g., Brown, et al. 1997] constraints and a penalty function. The elastic constraints admit solutions that would customarily be infeasible by charging a penalty per unit violation of such constraints. Elastic constraints are denoted [e.g., Brown, et al. 1997] by a dot over the relational operator (e.g., $\dot{\leq}$, $\dot{\geq}$). For ease of presentation, the elastic variables are excluded from the formulation, but are discussed later.

2. Formulation

Indices

m	mission area	{combatant, carrier, fighter...}
s	ship class	{DDG, DD21, CVX,...}
s_m	subset of ship classes that perform mission *m* For example $S_{carrier}$ =	 {CVX, CVN63, CVN65, CVN68}
p	production facility	{Bath, Ingals, News, Eboat, ...}
p_s	subset of facilities that produce ship class *s* For example P_{DDG} =	 {Bath, Ingals}
a	aircraft type	{JSFN, F18EF,...}
a_m	subset of aircraft types that perform mission *m* For example $a_{fighter}$ =	 {JSFN, F18EF, F18CD, F18AB, F14}
c	category of money	{SCN, OMN, APN...}
y,y'	Fiscal Year	{FY06, FY07, ..., FY25}

d	delivery year	{FY06, FY07, ..., FY25}
q	quantity produced	{0,1,2}
t	number of ships	{1,2,3,4}
i	cost increment	{1,2,3}
	Identifies segment of piecewise linear, non-convex cost functions.	

index data and dependencies

constyrs_{sp} — number of years required to build a ship of class *s* at facility *p* (produced in *y*, delivered in $d = y + \text{constyrs}_{sp} - 1$).

Data (Data units are shown in parentheses)

$\overline{\text{toapen}}_y$, $\underline{\text{toapen}}_y$ — penalty per unit violation of TOA in year *y* (FY99$M per FY99$M)

$\overline{\text{pcappen}}_{py}$, $\underline{\text{pcappen}}_{py}$ — penalty per unit violation of maximum and minimum production capacities for facility *p* in year *y* (FY99$M per worker)

mreqpen_m — penalty per unit violation of platforms required to perform mission *m*, mreq_m (FY99$M per platform)

otherScn_y — SCN cost in year *y* not directly associated with each procurement option includes money budgeted for Landing Craft Air Cushion, Service Craft procurement, transfer cost for ships procured, and post delivery cost for ships delivered (FY99$M)

frac — historical fraction of total SCN money required for ship outfitting cost (scalar)

otherCost_{cy} — fixed category *c* money cost in year *y* for platforms not considered in CIPA for procurement (FY99$M)

scost_{sydt} — amount of SCN money expended in year *y* if *t* units of ship *s* are ordered for delivery in year *d* (FY99$M)

apn5	historical fraction of total APN categories 1 thru 4 required for categories 5 thru 7 (scalar)
$acost_{adi}$	increment *i* procurement cost per aircraft of type *a* for delivery in year *d* (FY99$M)
b_{adi}	increment *i* fixed procurement cost (intercept) for delivery in year *d* of aircraft type *a* (FY99$M)
$\overline{inc}_{ayi}$, $\underline{inc}_{ayi}$	increment *i* upper and lower bound for the number of type *a* aircraft procured for delivery in year *y* (aircraft)
$omnShipB_{sy}$	OMN cost per ship in year *y* for class *s* ships below $breakPt_s$ (FY99$M per ship)
$omnShipA_{sy}$	OMN cost per ship in year *y* for class *s* ships above $breakPt_s$ (FY99$M per ship)
$omnAir_a$	OMN cost per aircraft of type *a* (FY99$M)
$bShipInv_s$	initial inventory of class *s* ships (ship)
$breakPt_s$	break point for OMN cost calculations for ship class *s* (ship)
$upShip_s$	maximum number of class *s* ships in inventory (ship)
$bAcInv_a$	initial inventory of type *a* aircraft (aircraft)
$\overline{toa}_y$, $\underline{toa}_y$	TOA budget band for year *y* (FY99$M)
$workers_{spydq}$	workers required at facility *p* in year *y* to build *q* ships of class *s* to be delivered in year *d* (worker)
$\overline{pcap}_{py}$, $\underline{pcap}_{py}$	maximum and minimum production capacities for facility *p* in year *y* (worker)

$oldShips_{sy}$	number ships of class *s* that must be retired by the end of year *y* (ship)
$oldAir_{ay}$	number aircraft of type *a* that must be retired by the end of year *y* (aircraft)
$bInv_{m}$	initial inventory of platforms available to perform mission *m* (platform)
$mreq_{m}$	number of platforms required to perform mission *m* (platform)

Decision Variables (units are shown in parentheses)

$SPROC_{sdpq}$	one if *q* ships of class *s* are procured for delivery in year *d* from facility *p*, and zero otherwise
AP_{ayi}	one if aircraft *a* is procured in cost increment *i* for delivery in year *d*, and zero otherwise
AMT_{sty}	one if *t* ships of class *s* incur SCN money cost in year *y*, and zero otherwise
$BREAK_{sy}$	one if the number of class *s* ships is greater than $breakPt_s$ in year *y*, and zero otherwise
$APROC_{adi}$	number of type a aircraft to procure in cost increment *i* for delivery in year *d* (aircraft)
$SRET_{sy}$	number of class *s* ships to retire in year *y* (ship)
$ARET_{ay}$	number of type *a* aircraft to retire in year *y* (aircraft)
$BUDGET_{cy}$	amount of money *c* to budget for year *y* (FY99$M)
INV_{my}	inventory of platforms available to perform mission *m* in year *y* (platform)

$OMNSB_{sy}$	number of class s ships below $breakPt_s$ in year y (ship)
$OMNSA_{sy}$	number of class s ships above $breakPt_s$ in year y (ship)
$TOTAIR_{ay}$	total number of type a aircraft operational in year y (aircraft)

Formulation

MINIMIZE: Penalties associated with $\overline{toapen}_y$, $\underline{toapen}_y$, $\overline{pcappen}_{py}$, $\underline{pcappen}_{py}$, and $mreqpen_m$.

SUBJECT TO:

SCN Constraints

$$otherScn_y + (1 + frac)*\left(otherCost_{SCN,y} + \sum_s \sum_t \sum_{d \geq y} scost_{sydt} * AMT_{std} \right) = BUDGET_{SCN,y} \qquad \forall y \quad (1)$$

$$\sum_{p \in P_s} \sum_{d = y + constyrs_{sp} - 1} \sum_q q * SPROC_{sdpq} = \sum_t t * AMT_{sty} \qquad \forall s,y \quad (2)$$

$$\sum_t AMT_{sty} \leq 1 \qquad \forall s,y \quad (3)$$

APN Constraints

$$(1+apn5)*\left(otherCost_{APN,y} + \sum_a \sum_i acost_{a,y+2,i} * APROC_{a,y+2,i} + b_{a,y+2,i} * AP_{a,y+2,i} \right) = BUDGET_{APN,y} \qquad \forall y \quad (4)$$

$$\underline{inc}_{ayi} * AP_{ayi} \leq APROC_{ayi} \leq \overline{inc}_{ayi} * AP_{ayi} \qquad \forall a,y,i \quad (5)$$

$$\sum_i AP_{ayi} \leq 1 \qquad \forall a,y,i \quad (6)$$

OMN Constraints

$$\sum_{s}\left(\text{omnShipB}_{sy}*\text{OMNSB}_{sy} + \text{omnShipA}_{sy}*\text{OMNSA}_{sy}\right) \qquad \forall y \quad (7)$$

$$\sum_{p\in P_s}\sum_{d\geq y}\sum_{q} q*\text{SPROC}_{sdpq} - \sum_{y'\leq y}\text{SRET}_{s,y'-1}$$
$$+ \text{bShipInv}_{s} = \text{OMNSB}_{sy} + \text{OMNSA}_{sy} \qquad \forall s,y \quad (8)$$

$$\text{breakPt}_{s}*\text{BREAK}_{sy} \leq \text{OMNSB}_{sy} \qquad \forall s,y \quad (9)$$

$$\text{OMNSA}_{sy} \leq \text{upShip}_{s}*\text{BREAK}_{sy} \qquad \forall s,y \quad (10)$$

$$\text{OMNSB}_{sy} \leq \text{breakPt}_{s} \qquad \forall s,y \quad (11)$$

$$\sum_{y'\leq y}\sum_{i}\text{APROC}_{ay'i} - \sum_{y'\leq y}\text{ARET}_{ay'-1} + \text{bAcInv}_{a} = \text{TOTAIR}_{ay} \qquad \forall a,y \quad (12)$$

Budget Constraint

$$\underline{\text{toa}}_{y} \dot{\leq} \sum_{c}\text{BUDGET}_{cy} \dot{\leq} \overline{\text{toa}}_{y} \qquad \forall y \quad (13)$$

Industrial Constraints

$$\sum_{s}\sum_{d}\sum_{q}\text{workers}_{spydq}*\text{SPROC}_{sdpq} \dot{\leq} \overline{\text{pcap}}_{py} \qquad \forall p,y \quad (14)$$

$$\sum_{s}\sum_{d}\sum_{q}\text{workers}_{spydq}*\text{SPROC}_{sdpq} \dot{\geq} \underline{\text{pcap}}_{py} \qquad \forall p,y \quad (15)$$

$$\text{SPROC}_{SSN774,d,News,q} = \text{SPROC}_{SSN774,d,Eboat,q} \qquad \forall d,q \quad (16)$$

$$\sum_{q}\text{SPROC}_{sdpq} \leq 1 \qquad \forall s,d,p \quad (17)$$

Retirement Constraints

$$\sum_{y' \leq y} SRET_{sy'} \;\geq\; oldShips_{sy} \qquad \forall s,y \quad (18)$$

$$\sum_{y' \leq y} ARET_{ay'} \;\geq\; oldAir_{ay} \qquad \forall a,y \quad (19)$$

Inventory Constraints

$$bInv_m + INV_{m,y-1} + \sum_p \sum_q \sum_{s \in s_m} q * SPROC_{sypq}$$

$$+ \sum_{a \in a_m} \sum_i APROC_{ayi} - \sum_{s \in s_m} SRET_{s,y-1} - \sum_{a \in a_m} ARET_{a,y-1} = INV_{my} \qquad \forall m,y \quad (20)$$

$$INV_{my} \;\dot{\geq}\; mreq_m \qquad \forall m,y \quad (21)$$

Non-negativity

$ARET_{ay} \geq 0 \;\; \forall a,y$; $SRET_{sy} \geq 0 \;\; \forall s,y$; $BUDGET_{cy} \geq 0 \;\; \forall c,y$; $INV_{my} \geq 0 \;\; \forall m,y$
$OMNSB_{sy} \geq 0 \;\; \forall s,y$; $OMNSA_{sy} \geq 0 \;\; \forall s,y$; $TOTAIR_{ay} \geq 0 \;\; \forall a,y$; $APROC_{adi} \geq 0 \;\; \forall a,d,i$

Binary Variables

$SPROC_{sdpq} \in \{0,1\} \;\; \forall s,d,p,q$; $AMT_{sty} \in \{0,1\} \;\; \forall s,t,y$; $AP_{ayi} \in \{0,1\} \;\; \forall a,y,i$
$BREAK_{sy} \in \{0,1\} \;\; \forall s,y$

Constraints (1) calculate the total amount of SCN money spent each year. For a specific year, constraint (2) relates the binary decision to produce *q* ships with the binary indication that *t* ships incur SCN cost in year *y*. For example, a DDG produced at Ingals for delivery in FY11 must be budgeted for in FY07. A DDG produced at Bath for delivery in FY11 must be budgeted for in FY06. Constraints (3) ensure that at most one quantity of ship class *s* is budgeted for in year *y*. Constraints (4) calculate the total APN money spent in a given year. Constraints (5) and (6) constitute a piecewise linear, non-convex approximation of aircraft procurement cost as a function of volume produced. For a given year, constraint (7) calculates the total amount of OMN money spent. Constraints (8) through (11) ensure the OMN budget reflects the number of operational ships in a given year based on procurements and retirements. Based on procurements, retirements,

and initial inventory levels constraint (12) counts the number of operational aircraft of type a in a given year. Constraints (13) ensure TOA either remains within a yearly budget band or an appropriate penalty is charged. Constraints (14) suggest that scheduled work be within the capabilities of each facility or a penalty is charged. Constraints (15) suggest that a minimum amount of work be scheduled at each facility so that it remains open or a penalty is charged. Constraints (16) schedule parallel, synchronous construction for SSN774 class submarines; SSN774 construction is a joint effort between Newport News Shipbuilding and Electric Boat. For a specific facility, constraints (17) ensure that at most one quantity of ships is procured for delivery in a given year. For example, in FY06, constraint (17) does not allow a procurement of three DDGs from Bath for delivery in FY11 and another separate procurement of four DDGs from Bath for delivery in FY11. Constraints (18) and (19) ensure that enough ships and aircraft are retired each year to meet cumulative retirement goals. For a specific year, constraint (20) calculates the inventory of ships or aircraft available to perform a mission; constraint (21) suggests that sufficient ships and aircraft should be available to satisfy mission requirements in a given year or a penalty is charged.

Representation of piecewise linear, non-convex cost functions is an important concept here. For illustrative purposes, the CIPA formulation exhibits two alternate representations of such functions.

Constraints (4) refer to a slope and intercept for each linear component, and all linear components appear here. Constraints (5-6) select at most one of these components for each aircraft and year. The resulting function yields for any aircraft volume the appropriate cost. Note that the components are not necessarily contiguous, and that it is possible that some procurement volumes are not allowed. This renders the *APROC* aircraft procurement variables semi-continuous over the range of volumes, and the domain of the cost function of these variables is piecewise linear and non-convex.

Alternately, for a special case in which there are only two piecewise linear cost components, separated by a single break-point, constraints (8) accumulate cost increments for *OMNSB* ships below the breakpoint and for *OMNSA* ships above the breakpoint. In

the concave case, there is economy of scale, and the above-breakpoint ships are less expensive. Constraints (9-11) make sure that the number of below-breakpoint ships reaches the breakpoint before any above-breakpoint ships are allowed.

C. ELASTIC VARIABLES AND PENALTIES

CIPA minimizes penalties associated with violating the budget band constraints (14), production constraints (15) and (16), and the inventory requirement constraints (22). Each constraint has an associated continuous non-negative elastic variable that takes on the positive magnitude of violation when the constraint is violated. Penalties are expressed in (FY99$M) dollars or dollar equivalents so they have meaningful values.

The elastic variables associated with not meeting budget requirements are $OVERTOA_Y$ and $UNDERTOA_y$. $OVERTOA_Y$ expresses the amount by which the upper budget band is exceeded and $UNDERTOA_y$ incurs positive value when the lower budget band is violated. Both variables incur a penalty of 1.07 (FY99$M) for each unit of violation. The Office of Management and Budget [1992] mandates a seven percent discount rate be used for public investment: "this rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years." Therefore, every penalty represents the cost of borrowing money or a foregone investment opportunity as appropriate in that year.

$OVERPROD_{py}$ and $UNDERPROD_{py}$ are the elastic variables associated with the production constraints. If a facility's production capability is exceeded, $OVERPROD_{py}$ expresses the excess; $UNDERPROD_{py}$ incurs positive value if a facility does not receive enough work to maintain its workforce. In CIPA production levels are measured by size of workforce. Each ship requires a facility-specific workforce in a given year of production. The penalty associated with positive values of $OVERPROD_{py}$ equates to overtime cost or time-and-a-half. Positive values of $UNDERPROD_{py}$ imply that a shipyard is underutilized and may lose critical industrial capabilities; it is more costly, double time, to violate the minimum production constraints.

The penalty variable associated with not meeting mission inventory requirements is $DEGRADE_m$, which expresses the deficiency when the force level does not meet a minimum requirement. The penalty associated with positive values of $DEGRADE_m$ is equivalent to the cost associated with procuring one more of the most expensive unit that performs the degraded mission area. This encourages procurement of units before failing to meet mission requirements.

When dealing with infeasible planning scenarios --- not an infrequent requirement --- elastic penalties offer considerable influence over when the infeasibilities will arise and how they might be resolved. In this vein, we argue that the discount rate for elastic penalties reflect the "fog of future planning," and suggest a higher discount than that justified by just the cost of capital. If we are forced to recommend optimally infeasible plans, better to arrange for violations to occur as far in the future as possible so that we have maximum time to prepare for and to treat the consequences.

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IV. IMPLEMENTATION AND ANALYSIS

A. MODEL IMPLEMENTATION

CIPA is implemented in the General Algebraic Modeling System (GAMS) [Brooke et al. 1997] with the CPLEX solver, Version 6.5 [ILOG 1999]. Over a 25-year planning horizon we use eight mission areas, 19 ship classes, five aircraft types, five production facilities, and three categories of money. The eight mission areas include six that are surface ship specific, one that is submarine specific, and one that is aircraft specific. The model has approximately 5,000 equations and 8,100 variables, of which a little over half are binary.

Like EPA/TOA, the first five years of the 25-year planning horizon are fixed in CIPA to reflect the Future Years Defense Plan. This provides accurate initial conditions that reflect the best intentions of Navy planners. CIPA schedules procurement only if production can be completed and delivery accepted within the planning horizon. *Therefore, CIPA does not schedule procurement past Fiscal Year 20 for ships and Fiscal Year 23 for aircraft.* The resulting end-effects produce far term (FY21-25) recommendations that diminish to zero procurements. While various methods exist to adjust or account for these end-effects, we feel this mimics current planning practices that treat far-term procurements as highly speculative.

CIPA is a mixed-integer linear program, and it is solved by branch-and-bound enumeration. The relative integer termination tolerance (the difference between the best integer solution and the best known lower bound, divided by the absolute value of the best integer solution) can influence the time required to solve each model instance. With a relative integer tolerance of five percent, CIPA generally runs in less than two minutes on a personal computer equipped with a Pentium II 333 MHZ processor and 192MB of ram. For planning purposes, we have used five percent. There is no ambiguity in this choice when comparing alternatives, as long as the competitors have integrality gaps (the

interval from the solution value to its lower bound) that are disjoint. Otherwise, a smaller relative tolerance can be applied with some likely increase in computation effort.

We also remind the reader that this tolerance is likely considerably better than the fidelity and resolution of the underlying planning data.

B. DATA

The data is presented by category in the same order it is encountered in the model formulation. Data for model excursions is presented as required later.

1. Ship Procurement Cost

Fixed SCN cost for platforms is taken from EPA/TOA. These non-discretionary fixed costs include money budgeted for Landing Craft Air Cushion vehicles and Service Craft procurement ($lcac_y$), first destination transfer cost ($xfer_y$), post delivery cost ($deliv_y$), and procurement cost for major platforms not controlled by CIPA ($otherCost_{SCN,y}$). This data is summarized in Table 1.

Fiscal Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
lcac	0	35	0	35	0	35	0	35	0	35
xfer	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
deliv	0	0	0	0	0	0	0	0	0	0
otherCost	532.7117	634.107	282.2524	516.1959	1660.915	391.8477	754.8223	1623.967	4143.728	6821.949

Fiscal Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
lcac	0	35	0	35	0	35	0	35	0	35
xfer	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
deliv	0	0	0	0	0	0	0	0	0	0
otherCost	10839.35	9289.781	10720.75	9961.839	11437.31	8017.665	8911.891	9953.479	7963.321	5307.852

Table 1. Fixed SCN cost data taken from the EPA/TOA model (FY99$M). The data represents money budgeted over twenty years for Landing Craft Air Cushion and Service Craft Procurement (lcac), first destination transfer cost (xfer), post delivery cost (deliv), and procurement cost for decisions not under consideration in CIPA (otherCost).

Piecewise linear approximations of the ship and submarine cost functions in EPA/TOA, shown in Appendix A, are used for procurement cost data ($scost_{sydt}$). Figure 6 shows the actual EPA/TOA cost function and its associated linear approximation for Fiscal Year 2006 Arleigh Burke class (DDG) destroyer procurements. These linear

approximations of the concave cost functions are *tangential* so that they overestimate procurement cost and provide a built in measure of conservatism. Some ships, including the CVX carrier and the Virginia class (SSN774) submarine, require cost saving advance procurement payments made one or two years before full procurement. Procurement cost data is summarized in Table 2.

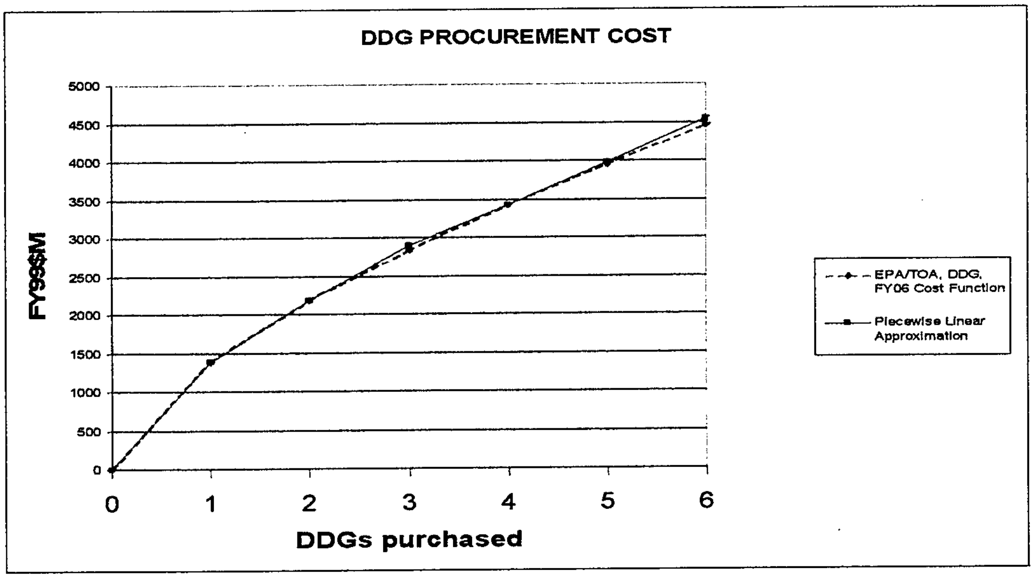

Figure 6. DDG-51 class ship procurement cost function and associated piecewise linear approximation (FY99$M). The procurement cost for all ships and submarines in CIPA is generated using tangential piecewise linear approximations of the EPA/TOA cost functions. For this particular example the maximum overestimation is 2.3 percent of 2.8 billion dollars.

Ship	Purchase Quantity (Range)	One Year Advance Procurement Cost Per Ship	Two Year Advanced Procurement Cost Per Ship	Cost Function Slope	Cost Function Intercept
DDG	1	0	0	1318.1380	0
DDG	2-3	0	0	726.1390	721.2010
DDG	4-6	0	0	561.6195	1173.2390
DD21	1-6	0	0	785	0
CVX	1-6	1388.1934	0	3923.6641	0
SSN774	1	213.7405	422.3919	1002.5445	0
SSN774	2	213.7405	422.3919	1940.7257	0
SSN774	3	213.7405	422.3919	2856.0560	0
SSN774	4-6	213.7405	422.3919	895.4740	174.9607
LHX	1	2117.0483	0	2117.0483	0
LHX	2-6	1272.2643	0	1272.2646	0

Table 2. CIPA ship and submarine procurement cost data (FY99$M). Procurement costs are tangential piecewise linear approximations of the EPA/TOA cost functions; each purchase quantity range contributes a linear approximation. Advanced procurement costs are included for the CVX class carrier and SSN774 class submarine. These are paid one and two years prior to full procurement.

2. Aircraft Procurement Cost

Aircraft procurement cost data is drawn exclusively from the EPA/TOA model. Fixed APN cost data consist entirely of the procurement cost of aircraft not discretionary for CIPA. The data is produced by subtracting CIPA-modeled aircraft cost from the total EPA/TOA aircraft procurement cost for APN categories one through four (APN categories one through four include money budgeted for procurement of combat, airlift, trainer, and other aircraft.). This data is presented in Table 3. Categories five through seven are money budgeted for aircraft modifications, spare and repair parts, and support equipment and facilities. These categories are estimated by a historic fraction of APN categories one through four in both EPA/TOA and CIPA. In CIPA, the fraction is denoted by *APN5* and is equal to 0.00107.

Fiscal Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
otherCost	4356.298	4874.093	5323.416	4721.599	5509.914	6101.367	6001.19	5822.762	5011.796	4305.832

Fiscal Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
otherCost	6011.112	5917.636	6212.508	6455.746	6710.751	5227.712	5942.438	6267.949	5695.527	5227.408

Table 3. Fixed APN cost data taken from EPA/TOA (FY99$M) for aircraft not modeled in CIPA.

The cost data for CIPA discretionary aircraft, $acost_{aydt}$, are piecewise linear approximations of the non-convex aircraft cost functions in EPA/TOA, shown in Appendix A. For Fiscal Year 2010, Figure 7 shows the actual EPA/TOA cost function and its associated linear approximation for Navy Variant Joint Strike Fighter (JSFN) procurements. The first JSFN is scheduled for Fiscal Year 2010 delivery. In CIPA, procurements of the JSFN in FY08 and FY09, for delivery in FY10 and FY11, are restricted to either 12 or 24 per year to represent opening new production lines. The associated estimates are taken directly from the EPA/TOA model. JSFN procurements in FY10 and later are based on a tangential piecewise linear approximation of the EPA/TOA cost function for FY10 procurements, which assumes that the Marine Corps and Air Force purchase 38 and 110 Joint Strike Fighters respectively. For Fiscal Years 10 through 25 JSFN procurements have been restricted to the range of 24 to 55. Procurement cost data is presented in Table 4.

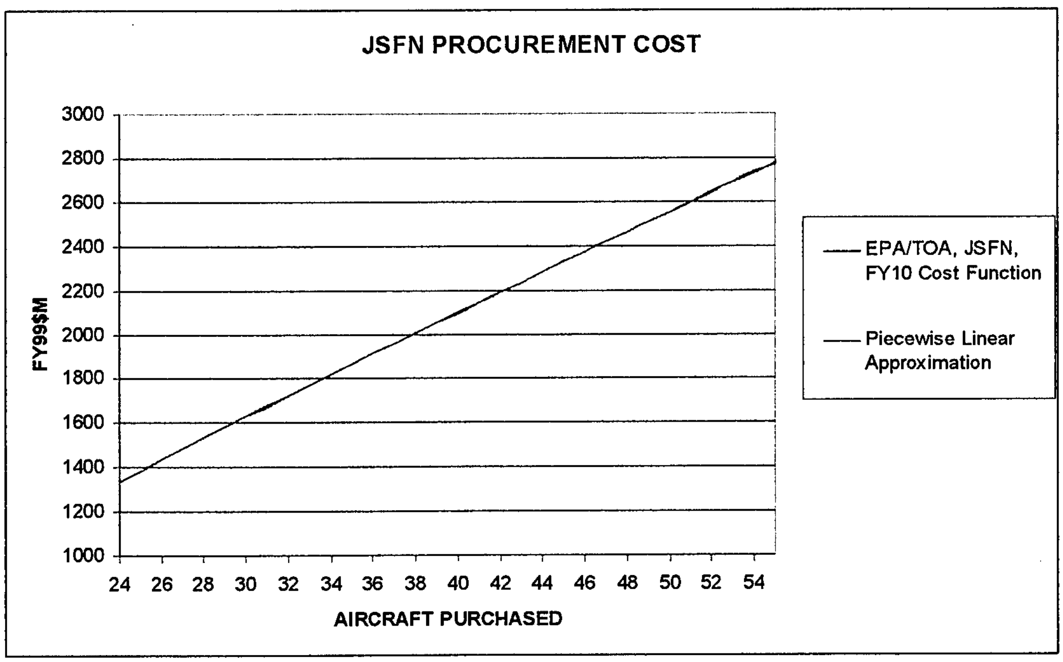

Figure 7. EPA/TOA procurement cost function for the Navy Variant Joint Strike Fighter (JSFN) and its associated tangential piecewise linear approximation. By visual inspection the cost are nearly equal. The maximum overestimate of the FY10 approximation is 0.23% of 3.5 billion dollars.

Aircraft	Purchase Quantity (24-30)		Purchase Quantity (31 40)		Purchase Quantity (41-55)	
	Slope	Intercept	Slope	Intercept	Slope	Intercept
JSFN	49.0856	156.8921	47.0401	217.3945	45.5081	278.2075
F18EF	45.2740	632.7160	39.9056	790.6317	36.2964	933.5517

Table 4. Aircraft procurement cost data for the Navy Variant Joint Strike Fighter (JSFN) and F18EF fighter (FY99$M). Procurement costs are tangential piecewise linear approximations of the associated EPA/TOA cost functions. For the F18EF, the above data is valid for FY06 through FY12: production ceases in FY12. For the first two years of JSFN procurements, FY08 and FY09, procurements have been limited to 12 and 24 to account for the new production line. In FY08 the procurement cost are 78.5082 and 72.076 per aircraft for 12 and 24 aircraft respectively. In FY09, the cost is 68.255 and 62.995 per aircraft for 12 and 24 respectively. The table data is valid for FY10 through FY25 for the JSFN.

3. OMN Cost

OMN cost data is taken from the EPA/TOA model. OMN fixed costs for platforms not modeled in CIPA are given in Table 5. Aircraft are approximated by a single cost factor of 0.8679 (FY99$M) per aircraft. For ships and submarines a two-component piecewise linear approximation is required to provide a closer approximation of OMN cost per ship. The components are separated by a single break point; all ships or submarines below the break point incur a higher cost than do the ships above the breakpoint. Figure 8 shows the actual EPA/TOA cost function for the SSN774 and its associated linear approximation. OMN cost data for ships and submarines is shown in Table 6.

Fiscal Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
otherCost	4839.916	4774.401	4765.315	4661.751	4669.371	4537.59	4482.305	4486.096	4489.99	4485.604

Fiscal Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
otherCost	4496.989	4495.705	4506.234	4514.38	4572.837	4852.36	5193.8	5531.815	5866.621	6247.427

Table 5. Fixed OMN cost data taken from EPA/TOA (FY99$M) for platforms not modeled in CIPA.

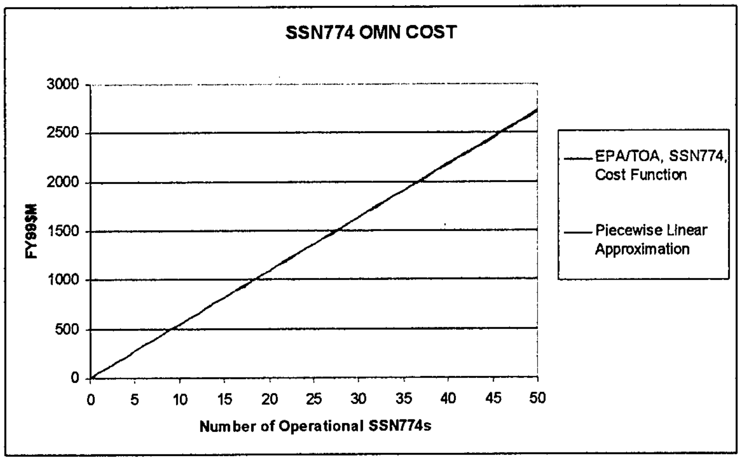

Figure 8. EPA/TOA OMN cost function for the Virginia class (SSN774) submarine and its associated tangential piecewise linear approximation. By visual inspection the function and its approximation look nearly identical. The maximum overestimate of the tangential approximation is 0.15% of 1.632 billion dollars.

Ship	Piecewise Linear Curve Break-Point	Cost per Ship Below Break-Point	Cost per Ship Above Break-Point
FFG	10	26.2000	26.1600
CG	16	53.4039	53.3087
DD	10	26.2625	26.2363
DD21	21	50.2267	50.1089
DDG	16	52.3340	52.2110
SSN774	16	54.6018	54.4080
SSN688	16	52.7135	52.5172
SSN21	3	66.4510	66.4510
CVX	5	526.9090	524.9517
CVN68	5	531.5264	528.7448
CVN63	2	255.3423	255.3423
CVN65	1	326.3699	326.3699
LHX	5	141.4739	141.2174
LHD	5	154.8960	154.5707
LHA	5	132.2465	132.2465
LSD36	1	44.6474	44.6474
LSD41	5	55.0482	54.9722
LPD4	5	42.6987	42.6987
LPD17	5	87.5529	87.4283

Table 6. OMN cost data for CIPA modeled ships and submarines (FY99$M). Costs are approximated on a two-component, linear piecewise approximation of the EPA/TOA OMN cost function. Ships and submarines below the break-point have a per unit cost that is more expensive than those above.

4. Budget Data

The budget data consist of upper and lower bounds for TOA; where TOA is defined as the sum of SCN, APN, and OMN monies. The bounds for the base case are equal to the maximum and minimum TOA observed in EPA/TOA. The upper and lower bounds are 51,042.6 (FY99$M) and 34,684.6 (FY99$M) respectively. Alternate budget bounds are explored later.

5. Production Facility Data

For each production facility, minimum and maximum production ranges have been provided by NAVSEA [Bissell 1999]. Production ranges are given in terms of employment levels expressed in number of workers. A minimum employment level represents the number of workers that must be employed to ensure no vital industrial capability is lost. The maximum employment levels represent the maximum production capability of the shipyard. The production ranges used are considered business sensitive proprietary data and are not shown here.

In CIPA, for a given ship type the base case assumes each facility can produce at most two ships per year. This limits the total number of ships produced per year to four for ships that are produced at multiple facilities. SSN774 class submarines are co-produced by Electric Boat and Newport News shipyards and have been limited to a total production of two per year to reflect initial purchase quantities. This restriction is relaxed in subsequent model excursions.

Employment requirements for each ship type, provided by NAVSEA [Alberts 1999], are facility specific and defined in terms of the average workers per year; each year of construction has unique employment requirements. Data for the LHX and CVX is not available, so it is approximated using the employment requirement for the LHD and CVN77 class ships. Again, the actual data is business sensitive, but a fabricated example is provided in Table 7 for illustrative purposes.

INGALS DDG PRODUCTION					
Year of Production	1ST	2ND	3RD	4TH	5TH
Average Workers Per Year	90	100	500	1000	400

Table 7. Production facility ship construction employment data. This fabricated example is provided for illustrative purposes because the actual data is business sensitive. Employment requirements by facility and ship type, similar in structure to this example, are used to calculate the production levels at each facility. In this example, if Ingals is building two DDGs, one in its second year of construction and one in its fourth year of construction, then its employment level is 1100.

6. Retirement Data

CIPA cumulative retirement goals are taken directly from EPA/TOA. The cumulative goals permit early retirement if it is beneficial. CIPA assumes that a retired platform is included in its platform inventory and incurs OMN cost in the year it is retired. Platform retirement goals are listed by year and type in Appendix B. For example, the entire inventory of DD class ships and F14 aircraft must be retired by FY11 and FY08 respectively. Specific retirement goals for each year until retirement are shown in Table 8 for the DD and F14.

CUMULATIVE RETIREMENT GOALS							
PLATFORM	FY06	FY07	FY08	FY09	FY10	FY11	FY12
DD	3	6	9	13	16	19	19
F14	13	38	74	74	74	74	74

Table 8. Cumulative retirement goals for the DD class ship and F14 aircraft taken from EPA/TOA. The cumulative goals allow CIPA to schedule early retirements if it is beneficial. The entire inventory of DDs and F14s must be retired by FY11 and FY08 respectively. Retirement goals for all CIPA platforms are in Appendix B.

7. Inventory and Mission Data

Initial platform inventory levels, taken from EPA/TOA, are the planned inventories at the end of Fiscal Year 2005 and can be found in Appendix B.

The Quadrennial Defense Review (QDR) [Department of Defense 1997] specifies a force level of 116 surface combatants, which includes FFG, DDG, DD, and CG class

ships. In CIPA, the surface ship combatant mission has been divided into the two missions of combatant-escort and combatant-cruiser: FFG, DDG, DD21, and DD class ships perform the combatant-escort mission and the CG class ship performs combatant-cruiser mission. While all the ships in the combatant-escort mission do not have the same capabilities, they do perform many of the same functions in a battle group. Additionally, the next generation of surface combatant, DD21, is being built to replace the FFG and DD ships. These divisions may oversimplify the battle group structure, but they prove adequate to provide insight into force levels. The CG class ship is given its own mission because of its unique air-warfare command capabilities. The mission requirement for the combatant-cruiser has been set to 27, which is the current inventory of CG class ships. The mission requirement for combatant-escort is 89: the QDR specifies 116 surface combatant requirement minus the combatant-cruiser requirement of 27.

The QDR requirement for Amphibious Ready Groups is 12 [Department of Defense 1997]. A typical Amphibious Ready Group consists of one assault ship; LHA, LHD, or LHX class ship; one LPD class ship, and one LSD class ship. In CIPA, the amphibious sea-lift mission is divided into three categories to mirror the Amphibious Ready Group composition. The missions are amphibious-assault, performed by LHD, LHA and LHX class ships; amphibious-platform; performed by LPD4 and LPD17 class ships; and amphibious-dock; performed by LSD36 and LSD41 class ships. Each mission requires 12 ships to meet the QDR requirements.

For submarines, the one CIPA mission is attack and corresponds directly with the QDR-specified 50 attack submarine requirement [Department of Defense 1997]. SSN774, SSN688, and SSN21 class submarines perform the attack mission.

The F14, F18AB, F18CD, F18EF, and JSFN aircraft perform the CIPA mission of fighter. According to the Director Air Warfare [1999], the typical Carrier Air Wing Tactical Air compliment is 14 F14 aircraft and 36 F18 aircraft. With the retirement of the F14 and the introduction of the JSFN, the vision for the Carrier Air Wing Tactical Air compliment for 2010 and beyond is an unidentified mix of 50 F18 and JSFN aircraft.

Total Tactical Aircraft (TACAIR) inventory requirements or goals are not available because planning is conducted based on squadron level inventories and allowances [Drohr 1999]. To facilitate force level planning, CIPA fighter requirements are generated using squadron level planning factors applied at the force level. The number of Primary Mission Authorized Aircraft (PMAA) is the base number used at the squadron level for determining aircraft requirements. Primary Training Aircraft Authorized (PTAA) is the number of aircraft authorized for training. The number of aircraft identified for development and testing is the Primary Development and Test Aircraft Authorized (PDAA). The formulas used to determine the number of Primary Aircraft Authorized (PAA) are as follows:

$$PAA = PMAA + PTAA + PDAA$$

Where:

$$PTAA = 0.25*PMAA \text{ and}$$

$$PDAA = 0.07*PMAA.$$

Pipeline or maintenance requirements must also be accounted for when determining the total number of required aircraft. A pipeline-planning factor of 1.12 is used. The QDR specifies 10 active air wings and one reserve air wing. As noted earlier the future carrier air wing will consist of 50 TACAIR. The CIPA TACAIR requirement is 550 aircraft if maintenance, training, and development are ignored. PAA equals 726 aircraft if we assume PMAA is 550. Applying the pipeline-planning factor to PAA yields a total requirement of 814 tactical aircraft.

C. COMPUTATIONAL RESULTS

1. Baseline Case

The baseline case is presented to provide a benchmark and direction for later excursions. All money is in Fiscal Year 99 million dollars.

Analysis of mission inventory levels for the baseline case reveals all mission requirements are satisfied except the combatant-cruiser and the attack submarine missions. Failure to meet combatant-cruiser mission requirements was anticipated and

can be attributed to the absence of a CIPA-modeled replacement platform for the CG class ship. Inventory levels fall below mission requirements starting in Fiscal Year 21, which is far enough in the future that adjustments can be made to correct this deficiency. The combatant-cruiser mission level is a known deficiency for the remainder of this analysis. Combatant-cruiser mission levels are shown in Figure 9.

Investigation of the attack inventory level deficiencies reveals that SSN774 production can not keep pace with retirement goals. This is because the dual-yard construction of SSN774 class ships limits production to two submarines per year. Attack mission inventory levels are shown in Figure 10. Relaxation of constraint (16), which schedules parallel and synchronous construction for SSN774 class submarines between Electric Boat and Newport News shipyards, is investigated in the next model excursion to allow production of four SSN774 class submarines per year.

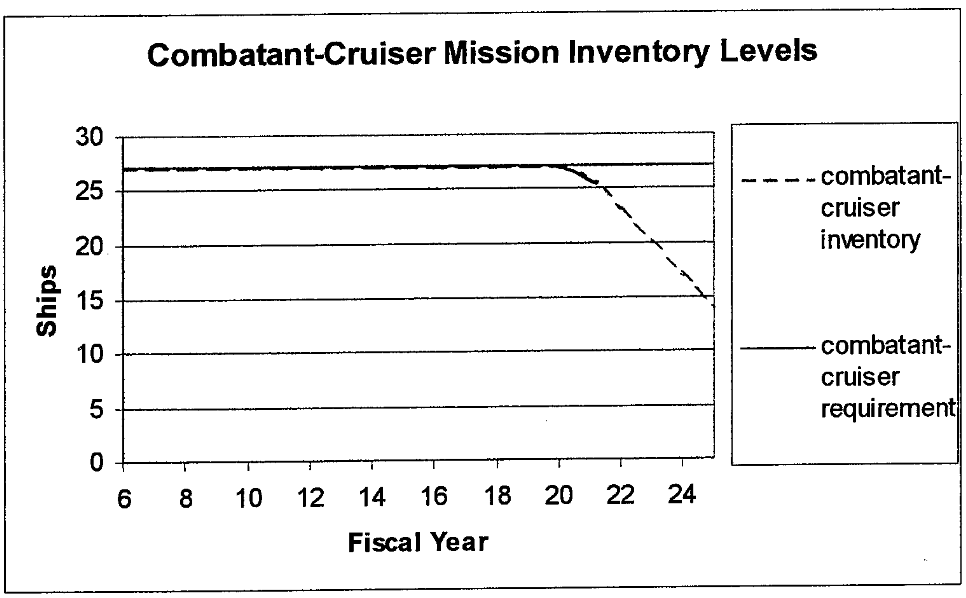

Figure 9. Combatant-cruiser mission inventory levels. Mission level deficencies, which begin in FY21, are anticipated and can be attributed to the absence of a CIPA-modeled replacement platform for the CG class ship. The combatant-cruiser mission level deficency is treated as a known problem for the remainder of this analysis.

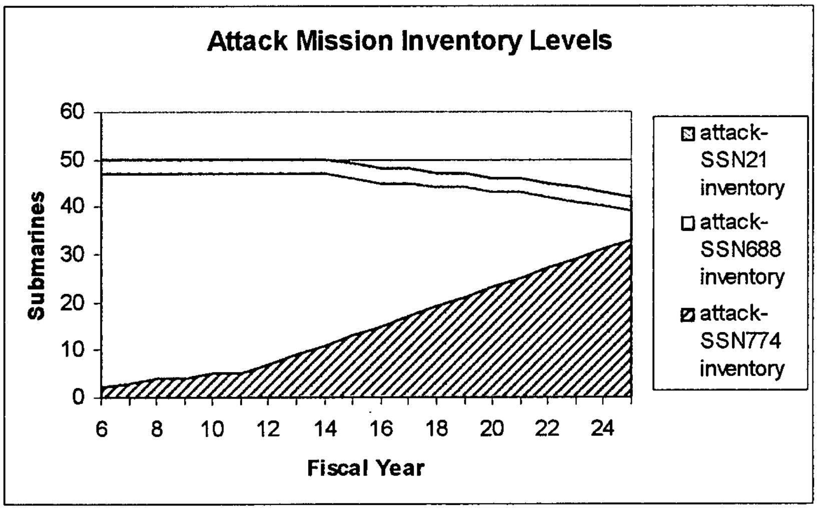

Figure 10. Baseline attack mission inventory levels. Beginning in FY15 the inventory level falls below the minimum requirement of 50 attack submarines. Production rates can not keep pace with retirement goals. Dual shipyard construction of the SSN774 class submarine is limited to two submarines per year. Subsequent model excursions allow a production rate of four SSN774 submarines per year.

CIPA recommends a budget that exceeds the baseline budget band in Fiscal Years 13, 17, 18, and 19. Investigation of Figure 11 reveals that these over-expenditures can be compensated for by lower spending rates in earlier and subsequent years. Additionally, the over-expenditure is far enough in the future to permit appropriate remedies.

CIPA schedules production only if it will be completed in Fiscal Year 25 or earlier. This end-effect assumption limits the construction that can be scheduled during the last years of the planning horizon. Production facility penalties for insufficient employment levels are incurred only in the first and last years of the planning horizon. Initial conditions force the former, and end-effects the latter.

CIPA recommends exceeding production capabilities at Bath, Ingals, and Newport News shipyards. Excess production at Bath occurs in FY10, but is likely within its surge capability. Excess production for Ingals and Newport News occur in FY17 and FY15 respectively. For Ingals, the excess production would require increasing the maximum employment level 12 percent. The maximum employment level at Newport

News would require a five percent increase. Production capability violations are large enough that they warrant further investigation but are far enough in the future that they can likely be reconciled.

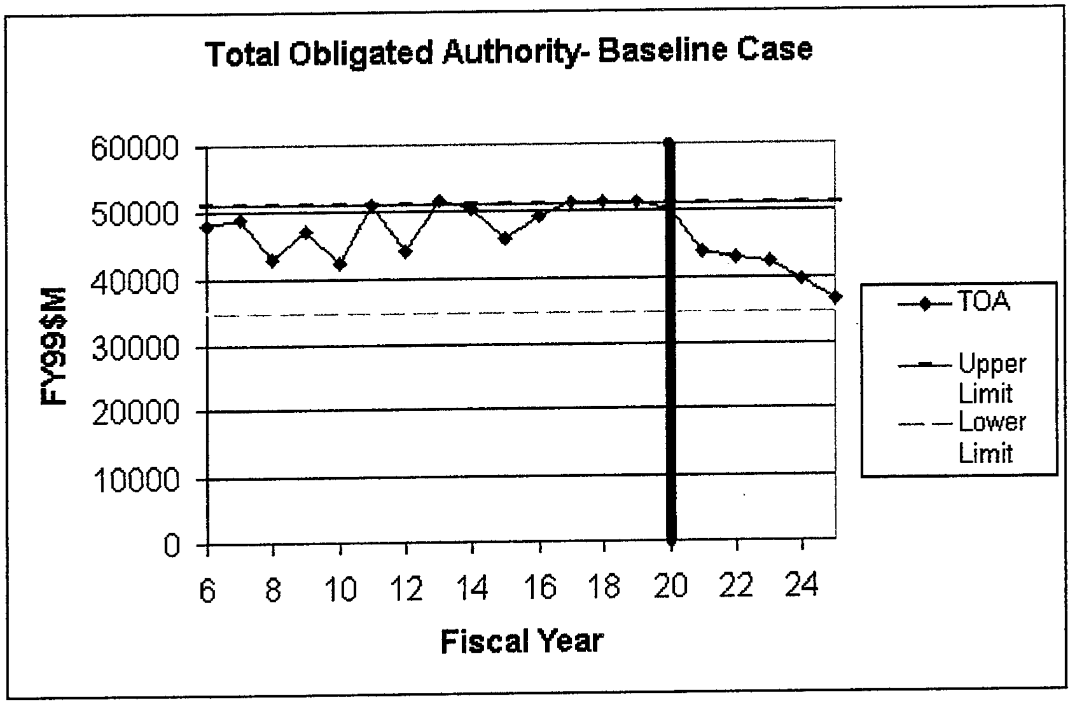

Figure 11. Total Obligated Authority cost for the baseline case (FY99$M). The CIPA budget recommends small over-expenditures in FY13, FY17, FY18, and FY19. For this case the budget band violations occur far enough in the future that they can be compensated for with under-expenditures in preceeding years. The FY20 through FY25 budgets demonstrate end-effects. CIPA schedules production only if it will be completed in FY25 or earlier. This limits construction and procurement in the last years of the planning horizon.

2. Excursion One - Increased SSN774 Production

The attack mission deficiency in the baseline case highlights the need for increased production of the SSN774 class submarine. Constraint (16) is relaxed to allow independent construction of SSN774 class submarines at Electric Boat and Newport News shipyards, which increases maximum yearly production from two to four. Increased production corrects the attack mission deficiency. However, it also curiously

recommends retiring all SSN21 class submarines by Fiscal Year 12. This can be attributed to the higher OMN cost of the SSN21 class submarine: each SSN21 class submarine costs approximately 12 million dollars more per year than the SSN774 class submarine. While the retirement of the SSN21 class submarine makes financial sense, it is too valuable to retire early. The retirements of the SSN21 submarine will be restricted in the next excursion to provide a more palatable recommendation. Figure 12 shows the composition of the attack mission inventory.

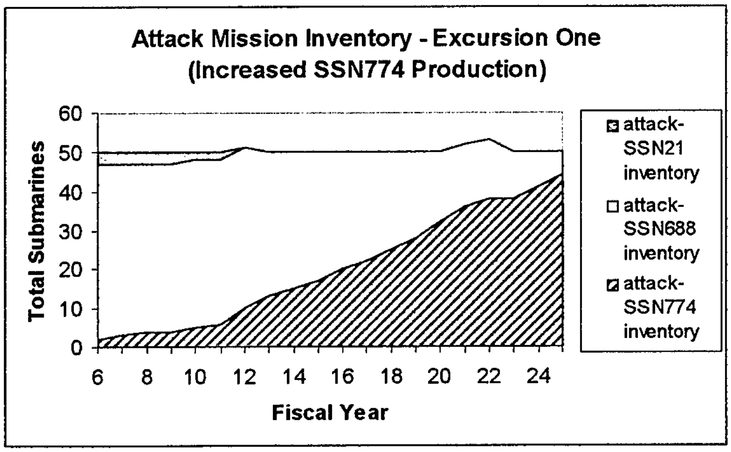

Figure 12. Attack Mission Inventory for Excursion One: Increased SSN774 Production. Increased production capacity for the SSN774 class submarine corrects the attack mission deficiency. However, it recommends retiring all SSN21 submarines early because of the higher OMN cost associated with the SSN21 class submarine in comparison to the SSN774 class submarine. While this may save money, it is not likely planners will allow early retirement of the SSN21 class submarine.

3. Excursion Two - Controlled SSN21 Retirements

The previous excursion identified the need to restrict SSN21 class submarine retirements to provide a more realistic force structure plan. For this excursion, the increased SSN774 production capabilities are retained and SSN21 class submarine retirements are not permitted in the planning horizon. As in the previous excursion, all mission inventory requirements, with the exception of the combatant-cruiser mission, are satisfied. Additionally, the recommended force structure plan makes sense. The CIPA generated force structure plan for excursion two is presented in Appendix C. Figure 13

presents the attack mission inventory associated with excursion two for comparison with excursion one.

CIPA recommends a budget that exceeds the upper budget band in Fiscal Years 16 and 18. The total amount of recommended over-expenditures is less for excursion two than the baseline case. As expected, the total amount expended over the entire planning horizon is greater for excursion two than the baseline because more SSN774's are produced. Figure 14 shows the TOA levels associated with excursion two and the baseline case.

Newport News Shipbuilding is the only shipyard required to exceed maximum employment levels for the recommended production plan. At approximately two percent, this is trivial. As in the baseline case, excursion two recommends employment levels below the required minimum in the first and last years of the planning horizon. Additionally, CIPA recommends employment levels below the required minimum in Fiscal Years 19 and 21 for Ingals shipyard. The theoretical layoffs associated with the recommended plan for Ingals are large enough to invite further investigation, but they are far in the future.

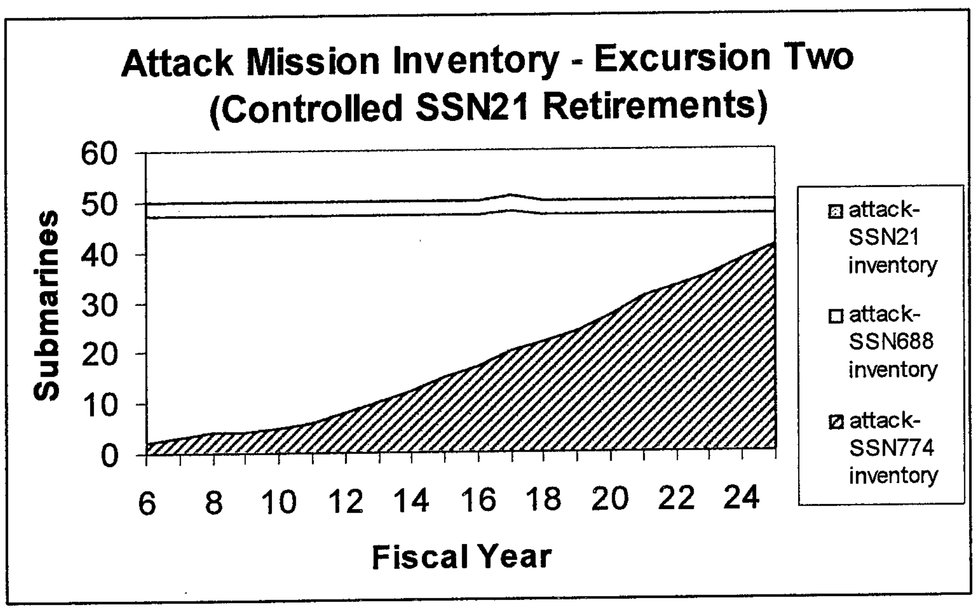

Figure 13. Attack Mission Inventory for Excursion Two: Controlled SSN21 Retirements. The attack mission inventory requirement of 50 attack submarines is satisfied by the CIPA recommended force structure plan.

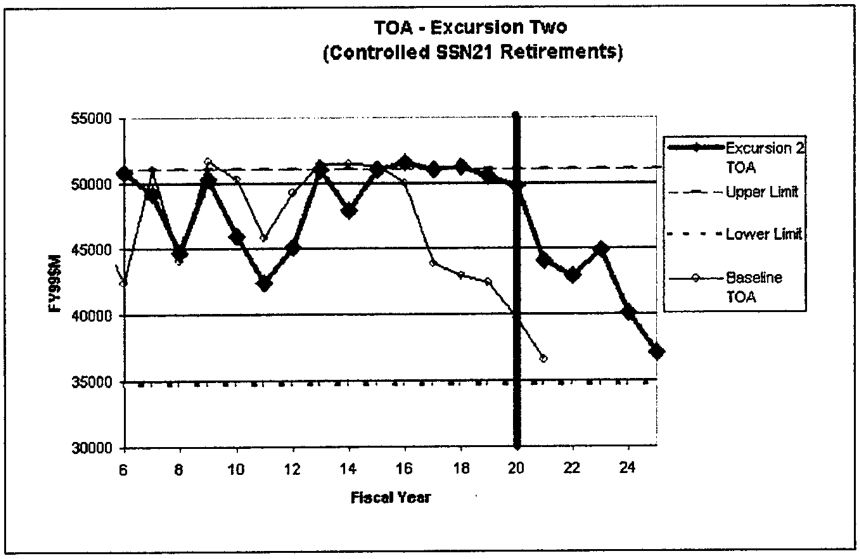

Figure 14. Total Obligated Authority for Excursion Two: Controlled SSN21 Retirements. In excursion two SSN774 production is increased to four per year and SSN21 retirements are controlled to eliminate unrealistic retirements. The graph shows that the total over-expenditures recommended in the baseline case exceed those of excursion two. However, as expected, increased production of SSN774 class submarines results in higher total expenditures over the entire planning horizon. The FY20 through FY25 budgets demonstrate end-effects. CIPA schedules production only if it will be completed in FY25 or earlier. This limits construction and procurment in the last years of the planning horizon.

4. Excursion Three - Reduced Budget Band

The budget band used in the previous CIPA model excursions is set to the maximum and minimum values observed in EPA/TOA over the 25-year planning horizon. This budget band may be too liberal. In excursion 3, the budget bands are reduced to plus or minus ten percent of the average TOA observed in EPA/TOA. The new upper and lower budget bands are 46,803 and 38,293 million dollars respectively. This lowers the upper band by 4,239 million and raises the lower bound by 3,608 million.

Reducing the budget band produces the first mission inventory deficiency not associated with production or platform replacement limitations. In Fiscal Year 20, the combatant-escort mission area has a deficiency of one ship. This deficiency occurs far in

the future, and can be offset by something as simple as delaying a planned retirement just one year. The combatant-escort mission inventory levels are shown in Figure 15.

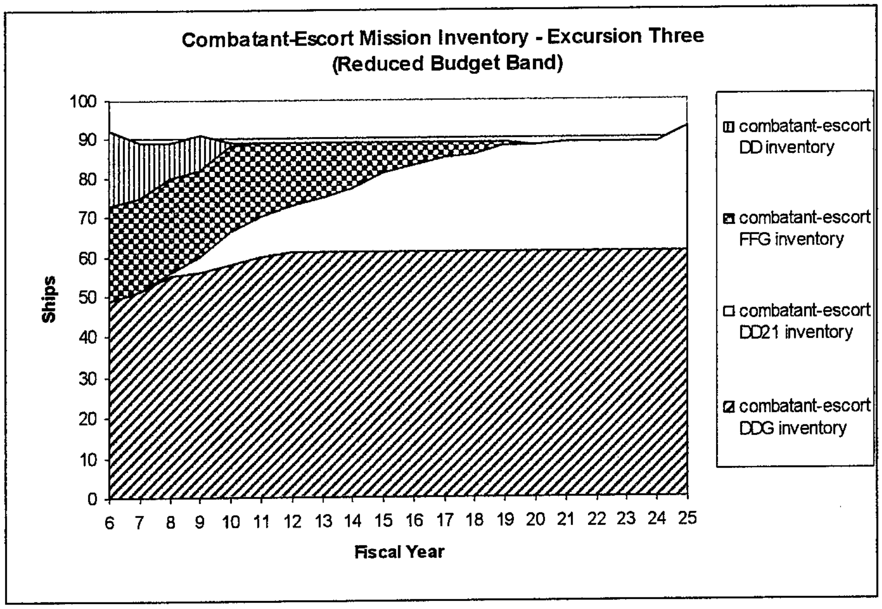

Figure 15. Combatant-escort Mission Inventory for Excursion Three: Reduced Budget Band. For excursion three the budget band is decreased by over 7000 million dollars from the previous budget band. The new budget band results in a combatant-escort mission deficency of one ship in Fiscal Year 20. This deficiency is easily dealt with by delaying a planned retirement.

Over-expenditures are required for multiple years in the CIPA-recommended budget for excursion three. Although excursion three violates its upper budget band more frequently and in larger quantities than excursion two, its total expenditures are far less than those of excursion two. This is accomplished with no appreciable loss in mission inventory levels, but with erratic production schedules that violate the minimum employment levels more frequently than excursion two. However, violations occur far enough in the future that they are most likely a function of CIPA's terminal production assumptions and can be corrected in future planning scenarios. Figure 16 shows the recommended budget levels for excursion two and three.

This is another scenario where CIPA over-expenditures can be balanced by lower spending in earlier and in subsequent years; however, this is fortuitous. We can

formalize the idea keeping track of cumulative over and/or under-expenditures by modifying constraint (13) as follows:

$$\sum_{y' \le y} \underline{toa}_{y'} \overset{\bullet}{\le} \sum_{c} \sum_{y' \le y} \text{BUDGET}_{cy'} \overset{\bullet}{\le} \sum_{y' \le y} \overline{toa}_{y'} \qquad \forall y \qquad (13a).$$

With this modification, any over- or under-expenditure is penalized in the year it occurs, and is carried forward and perhaps penalized in subsequent years as well. However, CIPA can avoid paying more penalties by finding funding patterns that balance cumulative over and/or under-expenditure as quickly as possible.

Repeating this excursion with the cumulative budget modification (13a), there are more over-expenditures year-by-year, but only one of these is a cumulative over-expenditure: 298 million in Fiscal Year 20.

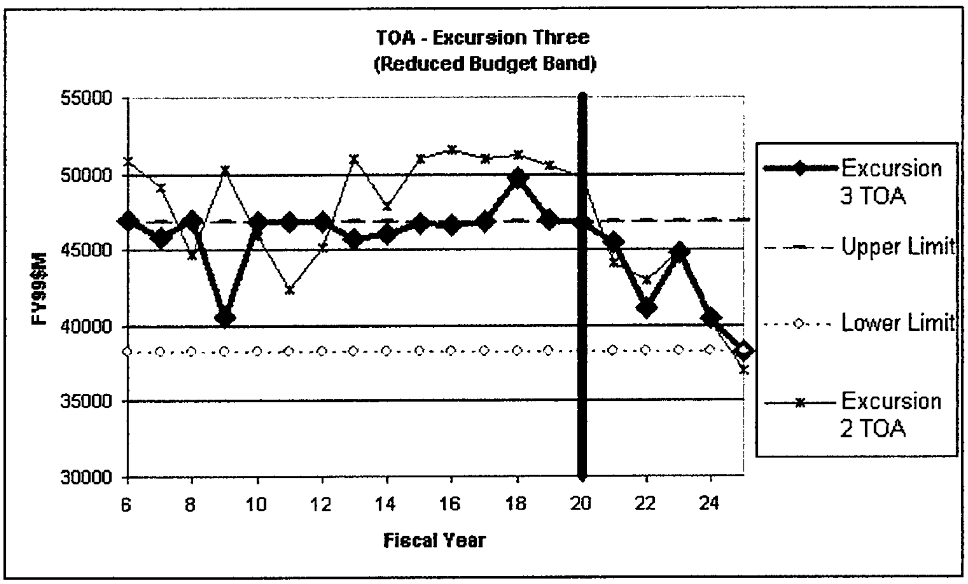

Figure 16. Total Obligated Authority for Excursion Three: Reduced Budget Band. For excursion three the budget band is reduced by over 7000 million dollars. The reduction in total expenditures for excursion three, when compared to excursion two, is accomplished with no loss in mission effectiveness. The cost savings result in erratic production schedules that violate production requirements more frequently than previous excursions. Production violations occur far enough in the future that they are most likely due to CIPA's terminal production assumptions and can be corrected in the future. The FY20 through FY25 budgets demonstrate end-effects. CIPA schedules production only if it will be completed in FY25 or earlier. This limits construction and procurement in the last years of the planning horizon.

5. Excursion Four - Increased Attack Mission Requirements

The 50 attack submarine QDR requirement has put serious strains on the attack submarine force. Analysts with the Force Structure IWARS component are unofficially evaluating a 55 submarine attack inventory requirement [Ruck 1999]. For excursion four the attack mission inventory requirement in CIPA is changed to 55 and evaluated within the restricted budget bands from excursion three.

Attack mission inventory level deficiencies, shown in Figure 17, occur from Fiscal Year 06 through Fiscal Year 12. Deficiencies are attributed to fixed production associated with the Fiscal Year Defense Plan procurements that dominate the initial planning years.

The requirement for an additional five submarines increases the total expenditures over the planning horizon, but does not significantly change the amount of over-expenditures. TOA levels are shown in Figure 18 for excursions three and four.

Production schedules improve for all shipyards for excursion four. The maximum employment levels are never violated and the minimum production levels are violated less than in the previous excursion.

A 55-submarine attack force is definitely attainable within the projected budget band. However, to attain the required 55 attack submarine level in the near term would require reevaluating retirements and procurements for the Fiscal Year Defense Plan period.

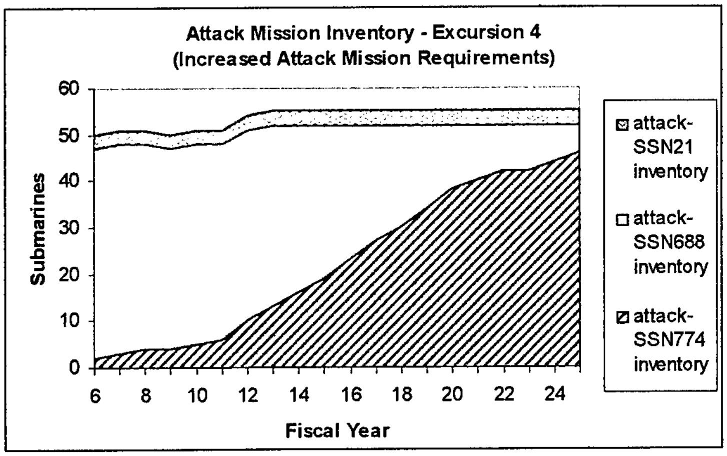

Figure 17. Attack Mission Inventory for Excursion Four: Increased Attack Mission Requirements. The mission inventory requirement for attack submarines is increased from 50 to 55 in excursion four and evaluated using the same budget bands as in excursion three. Mission level deficiencies occur in FY06 through FY12. The deficiencies are attributed to the fixed procurements associated with the Fiscal Years Defense Plan in the early years. Attack submarine retirements and procurements in the Fiscal Years Defense Plan period require reevaluation to attain the new inventory level in the near term.

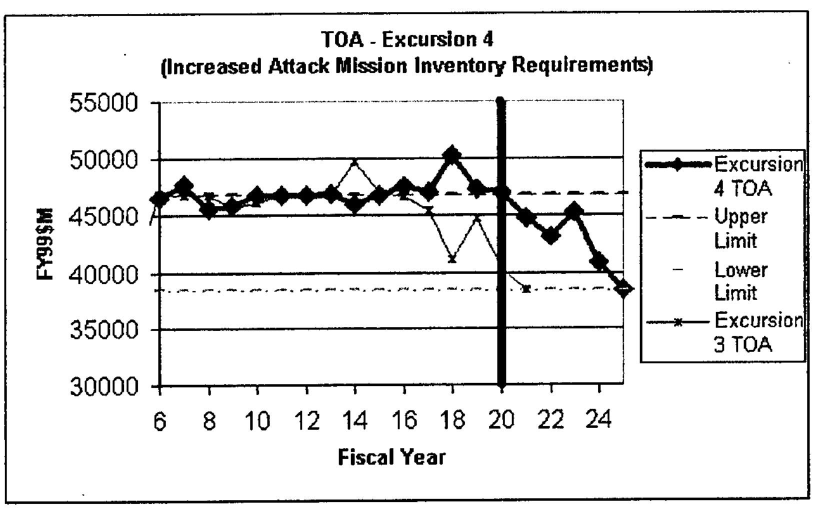

Figure 18. Total Obligated Authority for Excursion Four: Increased Attack Mission Level Requirement. Over-expenditures for excursions three and four are nearly identical. As anticipated, the total expenditures for the entire planning horizon increase for excursion four and production level violations decrease. The FY20 through FY25 budgets demonstrate end-effects. CIPA schedules production only if it will be completed in FY25 or earlier. This limits construction and procurement in the last years of the planning horizon.

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V. CONCLUSIONS AND RECOMMENDATIONS

CIPA augments existing tools by providing a recommended plan that automatically accounts for the integrated effects of budget constraints, production facility requirements, production capabilities, and mission inventory requirements. "What-if" scenarios generally run in under two minutes. CIPA output is easily explored and, as Chapter IV demonstrates, when coupled with a spreadsheet for data manipulation, can illuminate deficiencies resulting from resource conflicts.

CIPA models the majority of high-visibility navy procurement programs as discretionary and accounts for the other procurement programs by just setting aside these funds. Expanding CIPA to include all SCN and APN procurements can provide increased model flexibility and procurement insights.

While model output is easily analyzed with a spreadsheet, model manipulation requires an intimate knowledge of the General Algebraic Modeling System [Brooke et al. 1997]. A simple interface is required to make the system user friendly for the average analyst.

Like EPA/TOA, near-term CIPA procurements are fixed to reflect the Fiscal Years Defense Plan. This complicates analysis of emergent near-term requirements.

Workforce requirements for each ship type, which are facility specific and defined in terms of the average workers per year, are based on a representative platform. For example, the respective workforces for a DDG-class ship at Bath or Ingals shipyards are based on the projected employment requirements for the last ship to be produced at each facility. So, although production costs do account for learning, workforce levels do not. Workforce requirements that account for learning effects would be more realistic and potentially improve CIPA validity.

In CIPA, mission requirements are based solely on inventory levels and do not account for platforms that cross mission boundaries; for instance helicopters prosecute enemy submarines, conduct search and rescue missions, and provide surveillance and

targeting data on enemy surface combatants. Additionally, the mission requirements do not address the increased mission effectiveness achieved by combining different weapon platforms. Further research is required to refine inventory levels or mission areas to account for synergistic weapon effects and platforms that cross mission boundaries.

Despite its limitations, CIPA is the only known navy model that integrates APN and SCN procurements and provides force structure recommendations based on fiscal, industrial, and mission requirements. CIPA demonstrates the potential of military capital budgeting models for use by the Navy. It is the first step towards even smarter Navy procurement. Given the large amounts of resources, research and technology, and money involved with procurement of Navy capital investments, expansion of CIPA to a full-scale stand-alone model is warranted and highly recommended.

APPENDIX A. EPA/TOA COST FUNCTIONS

The EPA/TOA model uses a cost estimation relationship for SCN, APN, and OMN monies. The formulas associated with computing these monies are presented below.

SCN costs are calculated in EPA/TOA by summing the total procurement cost of all ships (*Totship*), total cost of outfitting all ships (*Totout*), total post delivery cost for all ships (*Totpost*), total cost for LCAC and Service Craft (*TotLCAC*), and total first destination transfer cost (*Totxfer*). *Totxfer, TotLCAC,* and *Totpost* are fixed by year. Outfitting cost, represented by *Totout*, is calculated by multiplying *Totship* by the scalar *frac*. For Fiscal Year 2006 (FY06) the formula (including some zeros applicable for this year) is:

$SCN = Totship + Totout + Totpost + TotLCAC + Totxfer.$

Where:

$Totship = \sum_{classes} Totcost_{class}$, with $classes = \{DDG51, FFG, CG, \ldots\}$,

$Totxfer = 0.001,$

$TotLCAC = 0,$

$Totpost = Post96/SCN96 * Totship = 0 * Totship,$ and

$Totout = Out96 / SCN96 * Totship = 0.0289 * Totship.$

The primary cost driver for SCN is *Totship* cost. The procurement cost (*Totcost*) for a specific ship type captures savings realized from workforce learning and increased purchase rates. The formula for the DDG51 ship class in FY06 is:

$$Totcost_{DDG51} = Qty * \left(T1cost * midpt^{Log_2(lslope)} * Qty^{Log_2(rslope)} \right) .$$

Where:

Qty = number ships purchased,

$T1cost$ = theoretical cost of first ship = 1.518,

$lslope$ = learning slope = 0.984,

$rslope$ = rate slope = 0.787,

$midpt = (cqFY05 + 1 + \mathrm{cqFY06} + \left(2 * \sqrt{(cqFY05+1) * cqFY06}\ \right))/4$,

$cqFY05$ = cum total quantity DDGs in FY05, and

$cqFY06$ = cum total quantity DDGs in FY06 .

APN money is comprised of seven categories. Categories 1 through 4 (APN4) include procurement cost for combat, airlift, trainer, and other aircraft. Categories 5 through 7 (APN5, APN6, APN7) include cost for aircraft modifications, spare and repair parts, and support equipment. Total cost (APN) are calculated by summing all APN categories. The formulas are:

APN = APN4 + APN5 + APN6 + APN7

Where:

APN4 = $\sum_{type} Totcost_{type}$, with type={F18EF, JSFN, F14, ...},

APN5 = 0.0692*(APN4 + APN6 + APN7),

APN6 = 0.1151*APN4, and

APN7 = 0.0692*APN4.

The primary cost driver for APN is $Totcost_{type}$. The procurement cost (*Totcost*) for a specific aircraft type captures savings realized from workforce learning and increased purchase rates. Air Force and the Marine Corps JSF procurement rates effect the Navy's $Totcost_{JSFN}$ and are assumed to be 110 (JSFAF) and 38 (JSFMC) per year respectively. The formula for the JSFN in FY10 is:

$$Totcost_{JSFN} = Qty * \left(T1cost * midpt^{Log_2(lslope)} * Qty^{Log_2(rslope)} \right) .$$

Where:

Qty = number aircraft purchased,

$priors$ = base (prior) production for the cost formula = 12,

$T1cost$ = theoretical cost of first aircraft = 280.615,

$lslope$ = learning slope = 0.857,

$rslope$ = rate slope = 0.929,

$comAF$ = commonality of Airforce and Navy JSF = 0.95,

$comMC$ = commonality of Marine Corps and Navy JSF = 0.80,

$midpt = (\mathrm{cqFY09} + 1 + \mathrm{cqFY10} + \left(2 * \sqrt{(cqFY09 + 1) * cqFY10}\ \right))/4$,

$cqFY09$ = 228.8 = cum total quantity JSFs in FY09, and

$cqFY10$ = Qty + (comAF*JSFAF + comMC*JSFMC) = Qty + 133.3
= cum total quantity JSFNs in FY10 .

OMN costs are estimated based on the number of navy civilian employees (*estCiv*), total ship tons (*shipTon*), and total ship electrical generation capacity (*shipGen*). The formulas are:

$$\left[(0.01374 * estCiv^{0.27284} * shipTon^{0.19394} * shipGen^{0.5361}) / 0.8528\right] - 0.01232$$

Where:

OtherShipTon = Total of all other ship tons,

OtherShipGen = Total of all other ship electrical generation capacities,

DONPAA = Number of Primary Aircraft Authorized for the Navy = 3704,

shipTon = OtherShipTon + tons*Qty,

shipGen = OtherShipGen + kw*Qty, and

$estCiv = 0.00171 * DONPAA^{0.5231} * shipTon^{0.8947}$.

APPENDIX B. PLATFORM RETIREMENT REQUIREMENTS

CIPA cumulative retirement goals are taken directly from EPA/TOA. The cumulative goals permit early retirement if it is beneficial. CIPA assumes that a retired platform is included in its platform inventory and incurs OMN cost in the year it is retired.

CUMULATIVE RETIREMENT REQUIREMENTS																				
PLATFORM	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
DDG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DD21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DD	3	6	9	13	16	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
FFG	0	0	2	2	2	2	5	8	11	14	16	18	21	24	24	24	24	24	24	24
CG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	7	10	13	16
SSN774	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSN21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSN688	0	1	2	2	3	4	6	9	12	15	17	20	22	25	27	30	33	36	39	42
CVX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CV63	0	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
CVN65	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
CVN68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
LHX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LHD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LHA	0	0	0	0	0	1	1	2	3	4	4	4	5	5	5	5	5	5	5	5
LSD36	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LSD41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
LPD17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPD4	0	2	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
JSFN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F18AB	16	16	19	29	35	40	56	99	135	184	184	184	184	184	184	184	184	184	184	184
F18CD	17	37	56	75	111	143	164	182	219	270	319	364	415	457	458	467	467	467	467	467
F18EF	0	0	0	0	0	0	0	6	12	19	25	30	36	42	48	61	79	104	131	163
F14	13	38	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74

Table 9. Platform retirement requirements taken form EPA/TOA. Specifying cumulative retirement goals allows CIPA to recommend early retirements if it is beneficial.

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APPENDIX C. CIPA FORCE STRUCTURE PLAN

CIPA recommendations are output to a comma-delimited text file and can easily be imported into a spreadsheet. In excursion two, SSN774 production is increased from two to four per year and SSN21 retirements are controlled to eliminate unrealistic retirements. The recommended CIPA force structure plan details mission and platform inventory levels, procurements, and retirements.

CIPA Force Structure Plan - Excursion Two (Controlled SSN21 Retirements)

SHIP AND SUBMARINE INVENTORY

Mission	Platform	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
combat	DDG	49	49	53	53	53	54	56	56	56	56	56	54	52	52	52	50	50	50	44	40
combat	DD21	0	0	1	4	8	12	14	17	19	21	23	27	31	35	37	39	39	41	45	49
combat	FFG	24	24	24	22	22	22	19	16	14	12	10	8	6	2	0	0	0	0	0	0
combat	DD	19	16	11	10	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
combat	Mission	92	89	89	89	89	91	89	89	89	89	89	89	89	89	89	89	89	91	89	89
combat-CG	CG	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	26	23	20	17	14
combat-CG	Mission	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	26	23	20	17	14
carrier	CVX	0	0	0	0	0	2	2	4	5	5	6	7	7	8	9	9	9	9	10	11
carrier	CVN68	9	9	10	10	10	9	9	8.77	8.77	8.77	5	4.34	4	4	3	3	3	3	2	1
carrier	CVN63	2	2	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
carrier	CVN65	1	1	1	1	1	0	0	0	0	.0	0	0	0	0	0	0	0	0	0	0
carrier	Mission	12	12	12	12	12	12	12	13.77	14.77	14.77	12	12.34	12	12	12	12	12	12	12	12
attack-	SSN774	2	3	4	4	5	6	8	10	12	15	17	20	22	24	27	31	33	35	38	41
attack-	SSN688	45	44	43	43	42	41	39	37	35	32	30	28	25	23	20	16	14	12	9	6
attack-	SSN21	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
attack-	Mission	50	50	50	50	50	50	50	50	50	50	50	51	50	50	50	50	50	50	50	50
amphibH	LHX	0	0	0	0	0	1	2	2	4	6	6	6	6	7	7	7	7	7	7	7
amphibH	LHA	5	5	5	5	5	5	4	4	3	1	1	1	1	0	0	0	0	0	0	0
amphibH	LHD	8	7	7	7	7	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5
amphibH	Mission	13	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
amphibS	LSD36	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
amphibS	LSD41	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
amphibS	Mission	13	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
amphibP	LPD4	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
amphibP	LPD17	7	9	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
amphibP	Mission	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12

Table 10. CIPA Force Structure Plan: Ship and Submarine Inventory. For example, in FY06 there are 45 SSN688 class submarines to perform the attack mission.

CIPA Force Structure Plan - Excursion Two (Controlled SSN21 Retirements)

AIRCRAFT INVENTORY

Mission	Platform	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
fighter	JSFN	0	0	0	0	24	24	78	133	188	243	298	304	334	334	334	334	356	375	399	426
fighter	F18EF	266	314	369	424	479	519	519	513	513	506	500	494	471	471	471	471	458	440	415	388
fighter	F18AB	184	165	165	165	149	149	144	95	49	49	0	0	0	0	0	0	0	0	0	0
fighter	F18CD	467	335	280	225	225	122	73	73	73	16	16	16	9	9	9	9	0	0	0	0
fighter	F14	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
fighter	Mission	991	814	814	814	877	814	814	814	823	814	814	814	814	814	814	814	814	815	814	814

Table 11. CIPA Force Structure Plan: Aircraft Inventory. For example, the CIPA recommended Navy JSFN inventory is 78 in FY12.

CIPA Force Structure Plan - Excursion Two (Controlled SSN21 Retirements)																						
Combatant: Procurements, Retirements, and Deliveries																						
Platform	Facility	action	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
DDG	Bath	procure	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DDG	Ingals	procure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DDG	total	procure	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DDG	Bath	deliver	1	1	2	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
DDG	Ingals	deliver	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DDG	total	deliver	3	2	4	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
DDG	retire	retire	2	0	1	0	0	0	0	0	0	0	2	2	0	0	2	0	0	6	4	0
DD21	Bath	procure	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	0	0	0	0
DD21	Ingals	procure	2	2	0	1	0	0	0	2	2	2	0	0	0	0	2	2	0	0	0	0
DD21	total	procure	4	4	2	3	2	2	2	4	4	4	2	2	0	2	4	4	0	0	0	0
DD21	Bath	deliver	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2
DD21	Ingals	deliver	0	0	1	1	2	2	0	1	0	0	0	2	2	2	0	0	0	0	2	2
DD21	total	deliver	0	0	1	3	4	4	2	3	2	2	2	4	4	4	2	2	0	[illegible]	4	4
DD21	retire	retire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FFG	retire	retire	0	0	2	0	0	3	3	2	2	2	2	2	4	2	0	0	0	0	0	0
DD	retire	retire	3	5	1	4	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CG	retire	retire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	3	3	3

Table 12. CIPA Force Structure Plan: Combatant Procurements and Retirements. For example, in FY06 CIPA recommends procuring two DD21 ships for production at Bath and two for production at Ingals: total DD21 procurement is four. CIPA recommends no DD21 retirements in FY06.

CIPA Force Structure Plan - Excursion Two (Controlled SSN21 Retirements)																						
Amphib: Procurements, Retirements, and Deliveries																						
Platform	Facility	action	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
LHX	total	procure	1	0	2	2	0	0	0	1	0	1	0	0	0	2	0	0	0	0	0	0
LHX	Ingals	deliver	0	0	0	0	0	1	1	0	2	2	0	0	0	1	0	1	0	0	0	2
LHX	total	deliver	0	0	0	0	0	1	1	0	2	2	0	0	0	1	0	1	0	0	0	2
LHX	retire	retire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0
LPD17	Avon	procure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPD17	total	procure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPD17	Avon	deliver	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPD17	total	deliver	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPD17	retire	retire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LHA	retire	retire	0	0	0	0	0	1	0	1	2	0	0	0	1	0	0	0	0	0	0	0
LHD	retire	retire	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
LSD36	retire	retire	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LSD41	retire	retire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
LPD4	retire	retire	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 13. CIPA Force Structure Plan: Amphibious Procurements and Retirements. For example, in FY06 CIPA recommends procuring one LHX for production at Ingals. No LHXs are to be delivered or retired in FY06.

CIPA Force Structure Plan - Excursion Two (Controlled SSN21 Retirements)																						
Aircraft: Procurements, Retirements, and Deliveries																						
Platform	Facility	action	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
SSN774	News	procure	0	0	0	1	1	1	0	0	2	2	0	0	2	2	0	0	0	0	0	0
SSN774	Eboat	procure	2	2	2	2	1	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0
SSN774	total	procure	2	2	2	3	2	3	2	2	4	4	2	2	4	4	0	0	0	0	0	0
SSN774	News	deliver	0	0	1	0	0	1	0	0	0	1	1	1	0	0	2	2	0	0	2	2
SSN774	Eboat	deliver	0	1	0	0	1	0	2	2	2	2	1	2	2	2	2	2	2	2	2	2
SSN774	total	deliver	0	1	1	0	1	1	2	2	2	3	2	3	2	2	4	4	2	2	4	4
SSN774	retire	retire	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0
SSN688	retire	retire	1	1	0	1	1	2	2	2	3	2	2	3	2	3	4	2	2	3	3	3
SSN21	retire	retire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 14. CIPA Force Structure Plan: Submarine Procurements and Retirements. For example, in FY06 CIPA recommends procuring two SSN774 submarines for production at Electric Boat. No SSN774 submarines are to be delivered or retired in FY06.

CIPA Force Structure Plan - Excursion Two (Controlled SSN21 Retirements)																						
Carrier: Procurements, Retirements, and Deliveries																						
Platform	Facility	action	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
CVX	News	procure	2	1	0	2	1	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0
CVX	total	procure	2	1	0	2	1	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0
CVX	News	deliver	0	0	0	0	0	2	0	2	1	0	2	1	0	1	1	0	0	0	1	1
CVX	total	deliver	0	0	0	0	0	2	0	2	1	0	2	1	0	1	1	0	0	0	1	1
CVX	retire	retire	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
CVN68	News	deliver	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CVN68	retire	retire	0	0	0	0	1	0	0.23	0	0	3.77	0.66	0.34	0	1	0	0	0	1	1	0
CVN63	retire	retire	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
CVN65	retire	retire	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 15. CIPA Force Structure Plan: Carrier Procurements and Retirements. For example, CIPA recommends procuring two CVX carriers in FY06. No CVX carriers are delivered or retired in FY06. CVN68 retirements are fractional and exhibit a curious jump in FY15. This jump turns out to be because FY16 is the first year available budget is exceeded, and CIPA retires CVN68-class carriers in FY15 to minimize over-expenditures and still meet mission requirements. If the fractional retirements prove nettlesome, CIPA inventory variables can be restricted to integer values. Regardless, this curiosity bears close review.

CIPA Force Structure Plan - Excursion Two (Controlled SSN21 Retirements)																						
Aircraft: Procurements, Retirements, and Deliveries																						
Platform	Facility	action	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
JSFN	procure	procure	0	0	0	0	24	0	54	55	55	55	55	24.54	30	0	0	0	30	24	24	27
JSFN	retire	retire	0	0	0	0	0	0	0	0	0	0	18.54	0	0	0	0	8	5	0	0	0
F18EF	procure	procure	48	48	55	55	55	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F18EF	retire	retire	0	0	0	0	0	0	6	0	7	6	6	23	0	0	0	13	18	25	27	32
F18AB	procure	procure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F18AB	retire	retire	19	0	0	16	0	5	49	46	0	49	0	0	0	0	0	0	0	0	0	0
F18CD	procure	procure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F18CD	retire	retire	132	55	55	0	103	49	0	0	57	0	0	7	0	0	0	9	0	0	0	0
F14	procure	procure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F14	retire	retire	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 16. CIPA Force Structure Plan: Aircraft Procurements and Retirements. For example, CIPA recommends procuring 24 JSFN aircraft in FY10. The fractional procurement and retirement recommendations for the JSFN in FY16 are allowed by CIPA.

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